Liebig,
Juices in the
Animal Body

RESEARCHES ON THE

Marbury Brown

MOTION OF THE

JUICES IN THE ANIMAL BODY;

AND THE EFFECT OF EVAPORATION IN PLANTS.

TOGETHER WITH AN ACCOUNT OF THE

ORIGIN OF THE POTATO DISEASE;

WITH FULL AND INGENIOUS DIRECTIONS FOR THE PROTECTION
AND ENTIRE PREVENTION OF THE

POTATO PLANT AGAINST ALL DISEASES.

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ILLUSTRATED WITH FIFTEEN FINE ENGRAVINGS.

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EDITOR'S PREFACE.

In the Editor's Preface to Baron Liebig's "Researches on the Chemistry of Food," in which the Author gave the results of his investigation into the constituents of the juice of the flesh, I mentioned that Baron Liebig had been led to study the subject of Endosmosis experimentally. The results of this investigation are contained in the following pages; and the reader will, I trust, be satisfied that the motions of the animal juices depend on something more than mere Endosmosis or Exosmosis, and that the pressure of the atmosphere, as well as its hygrometric state, by influencing the transpiration from the skin and lungs, are essentially concerned in producing these motions. At the same time, the present work is to be regarded, not as exhausting the subject, but, on the contrary, as only pointing out the direction in which inquiry is likely to lead to the most valuable results.

While it is proved that the mechanical causes of pressure and evaporation, and the chemical composition of the fluids and membranes, have a more direct, constant, and essential influence on the motion of the animal fluids, and, consequently, on the state of the health, than has been usually supposed, it is evident that very much remains to be done in tracing that influence under the ever varying circumstances of the animal body, and in applying the knowledge thus acquired to the purposes of hygiene and therapeutics. But it is equally obvious, that the above-mentioned mechanical and chemical causes are not alone sufficient to explain the phenomena of animal life, since they are present equally in a dead and in a living body; so that while every advance in physiology enables us to explain more facts on chemical and mechanical principles, something always remains, which, for the present, is beyond our reach, and which may forever remain so. However this may be, the facts established in this and in the preceding work of the Author have very materially extended the application of the well-known laws of physics and of chemistry to physiology, and have also furnished a number of the most beautiful instances of that infinitely wise, but exquisitely simple adaptation of means to ends, which characterizes all the works of the omnipotent Creator; but which is no where more admirably displayed, than in the arrangements, imperfectly known as they hitherto are, by which life is maintained.

In connection with the Author's remarks on the effects of evaporation in plants, and the consequences of its suppression, and with his opinions as to the origin of the potato disease, I beg to refer the reader to the Appendix for a very ingenious and apparently well founded plan for the protection of the potato plant against the terrible scourge under which it has lately suffered. The views of Dr. Klotzsch, the author of this plan, as to the nature of the disease, coincide remarkably with those of Baron Liebig, as explained in the present work.

WILLIAM GREGORY.

EDINBURGH, 3*d March,* 1850.

PREFACE.

THE present little work contains a series of experiments the object of which is to ascertain the law according to which the mixture of two liquids, separated by a membrane, takes place. The reader will, I trust, perceive in these researches an effort to attain, experimentally, to a more exact expression of the conditions under which the apparatus of the circulation acquires all the properties of an apparatus of absorption.

In the course of this investigation, the more intimate study of the phenomena of Endosmosis impressed on me the conviction that, in the organism of many classes of animals, causes of the motion of the juices were in operation, far more powerful than that to which the name of Endosmosis has been given.

The passage of the digested food through the membranes of the intestinal canal, and its entrance into the blood; the passage of the nutrient fluid outwards from the blood vessels, and its motion towards the parts where its constituents acquire vital properties,—these two fundamental phenomena of organic life cannot be explained by a simple law of mixture.

The Experiments described in the following pages will, perhaps, be found to justify the conviction that these organic movements depend on the transpiration and on the atmospheric pressure.

The importance of the transpiration for the normal vital process has, indeed, been acknowledged by physicians ever since Medicine had an existence; but the law of the dependance of the state of health on the quality of the atmosphere, on its barometric pressure, and its hygrometric condition, has been hitherto but little investigated.

By the researches contained in my examination of the constituents of the juice of flesh, as well as by those described in the present work, the completion of the second part of my Animal Chemistry has been delayed; but I did not consider myself justified in continuing that work until I had examined the questions suggested by, and connected with those researches.

DR. JUSTUS LIEBIG.

GIESSEN, *February*, 1850.

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ON

THE PHENOMENA

ACCOMPANYING

THE MIXTURE OF TWO LIQUIDS

SEPARATED BY

A MEMBRANE.

THE constituents of the food, which have assumed a soluble form in the alimentary canal, are thereby endowed with the property of yielding to the influence of every cause which, in acting on them, tends to change their place or the position which they occupy.* They are conveyed into the blood vessels, and from thence are distributed to all parts of the body.

The movement and distribution of these fluids, and of all the substances dissolved in them, exclusive of the mechanical cause of the contraction of the heart, by which the circulation of the blood is effected, depend, 1, on the permeability of the walls of all vessels to these fluids; 2, on the pressure of the atmosphere; and 3, on the chemical attraction which the various fluids of the body exert on each other.† The motion of all fluids in the body is effected by means of water: and all parts of the animal system contain, in the normal state, a certain amount of water.

Animal membranes, tendons, muscular fibres, cartilaginous ligaments, the yellow ligaments of the vertebral column, the cornea, transparent and opaque, &c., all contain, in the fresh state, more than half their weight of water, which they lose, more or less completely, in dry air.‡

On the presence of this water depend several of their physical properties. The fresh, opaque, milk-white cartilagesof the ear become, when dried, translucent, and acquire a reddish yellow color. Tendons, when fresh, are in a high degree flexible and elastic and possess a silky lustre, which they lose when dried. By the same loss of water they become, further, hard, horny, and translucent, and when bent, split into whitish bundles of fibres. The sclerotic coat is milk-white when fresh, and becomes transparent by desiccation.

When these substances, after having lost, by drying, a part of the properties which they possess in the fresh state, are again placed in contact with pure water, they take up, in 24 hours, the whole original amount of water, and recover perfectly those properties which they had lost. The opaque cornea, or sclerotic coat, which had become transparent by desiccation, again becomes milk-white, while the transparent cornea, which had been rendered opaque by drying, now becomes again transparent. The tendons, which, when dried, had become horny, hard, and translucent, now again become flexible and elastic, and recover their silky

* The food becomes soluble, and the fluids of the body are sent to all parts.

† General causes of their motion.

‡ Relation of animal tissues to water.

lustre. The fibrine and the cartilages of the ear, which desiccation had rendered horny and transparent, again become milk-white and elastic.

The power which the solids of the animal body possess of taking up water into their substance, and of being penetrable to water, extends to all fluids allied to water, that is miscible with it.* In the dried state, the animal solids take up fluids of the most diverse natures, such as fatty and volatile oils, ether, bisulphuret of carbon, &c. This permeability to fluids is possessed by animal tissues in common with all porous bodies; and no doubt can be entertained, that this property is determined by the same cause which produces the ascent of fluids in narrow tubes, or in the pores of a sponge; phenomena, which we are accustomed to include under the name of capillary action.

One condition, essential to the permeability of porous bodies for fluids (or their power of absorption), is their capability of being moistened; or the attraction which the particles of the fluid and the walls of the pores or tubes have towards each other.† A second condition is the attraction which one particle of the fluid has to another. We have no means of estimating the absolute size of the particles or molecules of a fluid, such as water, but they are certainly infinitely smaller than the measurable diameter of a tube, or of the pores of a porous body. It is obvious, therefore, that in the interior of a capillary tube or pore, filled with a fluid, only a certain number of the fluid molecules are in contact with the walls of the tube, and attracted by them; while in the middle of the tube, and from thence towards its parietes, fluid molecules must exist which only retain their place in virtue of the attraction which the molecules, attracted by the parietes, exert on those not so attracted; that is, by the cohesive attraction of the fluid.

Liquids flow out of capillary tubes, which are filled with them, only when some other force or cause acts, because capillary attraction cannot produce motion beyond the limits of the solid body which determines the capillary action.

The penetration of a fluid into the pores of a porous body, is the result of capillary attraction; its expulsion can be affected by a mechanical pressure; and may be accelerated by increasing this pressure, and by all such causes as diminish the mutual attraction of the fluid molecules, or the attraction of the walls of the pores for those molecules. The condition most favorable to the passage of a fluid through the pores of a porous substance under pressure, is when one fluid molecule can be displaced so as to glide away over another.

The slightest pressure suffices to expel the displaceable particles of water from a sponge; a higher pressure is required to express the same fluid from bibulous paper; and a pressure much higher still is necessary in order to cause water to flow out of moist wood.‡ We may form some idea of the force with which porous organic substances, such as dry wood, absorb and retain water, if we remember, that by inserting of wedges of dry wood in proper cuts, and subsequently moistening them, rocks may be split and fractured.

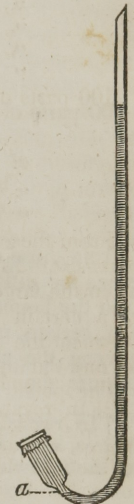
When we compare with the properties just enumerated, which belong to all porous bodies, those properties which are observed in animal substances under the same circumstances, it appears plainly that these animal substances have pores in certain directions;§ although these openings are so minute that they are not, in the case of most tissues, perceptible, even with the aid of the best microscopes.

It has been mentioned that tendons, ligaments, cartilages, &c., contain, in the fresh state, a certain amount of water, which, according to all experiments made on the subject, is invariable; and that several of their properties depend on the presence of this water.‖ (Chevreul.) When these substances, wrapped in bibulous paper, are subjected to a powerful pressure, a certain proportion of this water is expelled. Fresh and flexible vessels lose, in this way, 37.6 per cent., and the yellow ligaments of the vertebræ lose 35 per cent. of water. This property, namely, that of losing water under pressure, is only found in porous substances. It is obvious that by pressure, that is, by diminution of the size of the pores, only that portion of

* The tissues absorb other fluids. † The moistening of porous bodies.
‡ Prodigious force with which porous bodies absorb water.
§ Animal tissues are porous.
‖ Amount of water expelled by pressure from tissues.

water can be pressed out which is not retained by chemical attraction.* It is in the highest degree worthy of notice, that this water, not chemically combined, seems to have the greatest share in the properties which these animal substances possess in the fresh state, for the pressed tendons and yellow ligaments become transparent; the former lose their flexibilty, the latter their elasticity ; and if laid in water, they recover these properties perfectly. In the pores of a porous substance, the fluid molecules are retained by two kinds of attraction, namely, by the affinity which is exerted between the walls of the pores and the molecules of the fluid, and by the cohesion which acts between the molecules of the fluid itself. It would appear as if the molecules of water were thus brought into different states, and this seems to be the cause of the differences observed in the properties of these animal substances when they contain different proportions of water.

Fig. 1.



†If the wide opening of the tube, Fig. 1, be tied over with a portion of bladder, and water poured into the wide part of the tube, as far as the mark *a*, we shall find that, when mercury is poured into the upright narrow part of the tube, to a certain height, the whole external surface of the bladder becomes covered with minnte drops, which, if the column of mercury be made a few lines higher, unite, so as to form large drops. These continue to flow out uninterruptedly, if mercury be added, so as to keep the column at the same height, till at last the wide part of the tube is emptied of water and filled with mercury.

Solution of salt, fat oil, alcohol, &c., behave exactly as water does; under a certain pressure these fluids pass through an animal membrane, just as water does through a paper filter.

The pressure required to cause these liquids to flow through the pores of animal textures depends on the thickness of the membrane, as well as on the chemical nature of the different liquids.

Through ox-bladder, $\frac{1}{10}$th of a line ($\frac{1}{120}$th of an inch) thick, water flows under a pressure of 12 inches of mercury.‡ A saturated solution of sea salt requires from 18 to 20 inches ; and oil (marrow oil) only flows out under a pressure of 34 inches of mercury.

When the membrane used is the peritoneum of the ox, $\frac{1}{20}$th of a line, ($\frac{1}{240}$th of an inch) in thickness, water is forced through it by 8 to 10 inches, brine by 12 to 16 inches, oil by 22 to 24 inches, and alcohol by 36 to 40 inches of mercury.

The same membrane from the calf, $\frac{1}{66}$th of a line ($\frac{1}{792}$d of an inch) in thickness, allows water to pass through under the pressure of a column of water 4 inches high ; brine passes under a pressure of 8 to 10 inches of brine, and oil under a pressure of 3 inches of mercury.

In making experiments of this nature, we observe that, after they have continued for some time, the pressure required to force the liquid through the membrane does not continue equal. If during the first 6 hours a pressure of 12 inches of mercury were necessary, we often find that after 24 or 36 hours, 8, or even 6 inches will suffice to produce the same effect, obviously because by long-continued contact with water, the membrane undergoes an alteration, in consequence of which the pores are widened.

From these experiments it appears, that the power of a liquid to filter through an animal membrane bears no relation to the mobility of its particles ;§ for under a pressure which causes water, brine, or oil to pass through, the far more mobile alcohol does not pass.

The capacity of the animal membrane for being moistened by, and its power of absorbing, the liquid, have a certain share in producing the result of its filtration through the membrane.‖

The following table will show this fact:

* The portion of water not chemically combined, has the greatest share in the properties of the tissues.
† Pressure required to cause water and any other liquids to pass through membranes.
‡ The pressure varies with different liquids.
§ The passage of liquids through membranes not in proportion to their fluidity.
‖ The absorbent power of the membrane for the liquid has a share in the effect.

100 parts, by weight, of dry ox-bladder, take up in 24 hours,—

of pure water	268	volumes
„ saturated solution of sea salt (brine)	133	„
„ alcohol of 84 per cent.	38	„
„ oil of marrow*	17	„

100 parts, by weight, of ox-bladder, take up in 48 hours,—

of pure water	310	parts by weight
of a mixture of $\frac{1}{3}$ water and $\frac{2}{3}$ brine	219	„
„ „ $\frac{1}{2}$ „ $\frac{1}{2}$	235	„
„ „ $\frac{2}{3}$ „ $\frac{1}{3}$	288	„
„ „ $\frac{1}{2}$ alcohol $\frac{1}{2}$	60	„
„ „ $\frac{1}{3}$ „ $\frac{2}{3}$	181	„
„ „ $\frac{1}{4}$ „ $\frac{3}{4}$	290	„

100 parts of dry pig's bladder take up in 24 hours,—

of pure water	356	volumes
„ brine	159	„
„ oil of marrow	14	„

From these experiments it appears that the absorptive power of animal membranes for different liquids is very different. Of all liquids, pure water is taken up in the largest quantity; and the absorptive power for solution of salt diminishes in a certain ratio as the proportion of salt increases. A similar relation holds between the membranes and alcohol; for a mixture of alcohol and water is taken up more abundantly the less alcohol it contains.[1]

([1]) In regard to this property, membranes differ in no respect from other animal textures, as was long ago proved by Chevreul. This distinguished philosopher found that the following substances absorbed, in 24 hours, of water, brine, and oil,—

	Cubic Centimetres Water.	C. C. Brine.	C. C. Oil.
100 grammes of cartilage of the ear	231	125	—
100 „ tendons	178	114	8.6
100 „ yellow ligaments of spine	148	30	7.2
100 „ cornea	461	370	9.1
100 „ cartilaginous ligaments	319	—	3.2
100 „ dry fibrine absorbed	301 of water and 148 of alcohol of 69 per cent. (Liebig.)		
100 „ „ „	184 parts by weight or 154 by volume of brine.		

Animal membranes do not acquire, by absorbing alcohol or oil, those properties which they exhibit when saturated with water.† A dried bladder continues hard and brittle in alcohol and oil; its flexibility is in no degree increased by absorbing these liquids. When tendons, ligaments (Chevreul,) the yellow ligaments of the spine, or bladder, saturated with oil, are placed in water, the oil is completely expelled, and they take up as much water as if they had not previously been in contact with oil.

It has been mentioned, that 100 parts of animal membrane (dry ox-bladder) absorb in 24 hours 268, in 48 hours 310 volumes of water, and only 133 of saturated solution of salt. It follows, of course, that when the bladder, saturated with water by 48 hours' contact, and well dried in bibulous paper, without pressure, to remove superfluous water, is strewed with salt, there is formed, at all points where salt comes in contact with the water filling the open pores, a saturated solu-

* Absorption of different liquids.

† Effects of oil, salt, &c., on membranes when dry, and when in the moist state.

tion of salt, the salt contained in which diffuses itself equally in the water of the bladder. Of the 310 volumes of water which become thus saturated with salt, only 133 volumes are retained in the bladder; and in consequence of this diminution of the absorbent power of the bladder for the brine, 177 volumes of liquid are expelled, and run off in drops from the surface of the bladder.

Membranes, fibrine, or a mass of flesh, behave exactly in a similar manner when in contact with alcohol. If placed in alcohol in the fresh state, that is, when they are thoroughly charged with water, there are formed, at all points where water and alcohol meet, mixtures of the two, and as the animal texture absorbs much less of an alcoholic mixture than of pure water, more water is, of course, expelled, than alcohol taken up.

9·17 grammes of bladder, fresh, that is saturated with water (in which are contained 6·95 grammes of water, and 2·22 of dry substance,) when placed in 40 cubic centimetres of alcohol, weigh, at the end of 24 hours, 4·73 grammes, and have, consequently, lost 4·44 grammes.* In the 4·73 grammes which remain, are 2·22 grammes of dry bladder, and, of course, 2·51 grammes of liquid. If we assume that this liquid has the same composition as the surrounding mixture (which is found to contain 84 parts of alcohol to 16 of water,) it will consist of 2·11 grammes of alcohol and 0·40 of water; and consequently, of the 6·95 grammes of water originally present, 6·45 grammes have been expelled, and replaced by 2·11 grammes of alcohol. For 1 volume of alcohol, therefore, retained by the bladder, rather more than 3 volumes of water have been expelled from it.

† Since, in this case, so much more water is expelled than is taken up of alcohol, the first result is a shrinking of the animal substance.(1)

If the bladder could take up or absorb equal volumes of brine and water, or of alcohol and water, then when the fresh bladder was strewed with salt, or laid in alcohol, the volume of the absorbed liquid would be unaltered, and an equal volume of saline solution, or of diluted alcohol, would be retained by the animal tissue. But since the absorbent power of the tissue for water is diminished by the addition of salt, or of alcohol, it follows plainly, that a certain quantity of water must be expelled as soon as its character is changed by the addition of one of these substances.

The relation of bladder, fibrine, and other animal substances, when saturated with water, to alcohol and brine, proves, that the shrinking (diminution of volume) of these tissues does not depend on a simple abstraction of water in virtue of the affinity of alcohol and of salt for that liquid; for it is quite certain that the attraction of alcohol to water, and that of water to alcohol, are respectively equal.‡ The attraction of the water within the tissue for the alcohol without, is just as strong as the power of the alcohol without to combine with the water within. Less alcohol is taken up, and more water given out, because the animal tissue has less attraction for the mixture of alcohol and water than for pure water alone. The alcohol without becomes diluted, the water within becomes mixed with a certain proportion of alcohol, and this exchange is only arrested when the attraction of the water for the animal tissue, and its attraction for alcohol, come to counterpoise each other.

If we regard a piece of skin, or bladder, or fibrine as formed of a system of capillary tubes, the pores or minute tubes are, in the fresh state, filled with a watery liquid, which is prevented from flowing out by capillary attraction.

But the liquid contained in these capillary tubes flows out of them as soon as its composition is altered by the addition of salt, alcohol, or other bodies.

(1) Fibrine and other animal matters exhibit results quite similar to those obtained with bladder. 26·02 grammes of fibrine saturated with water (containing 6·48 grammes of dry fibrine and 19·54 of water) were reduced, in 45 grammes of absolute alcohol, to 16·12 grammes, losing, therefore, 9·90 grammes. Admitting the absorbed liquid to have the composition of the unabsorbed residue (70 per cent. of alcohol,) it appears, that for 1 volume of alcohol absorbed by fibrine rather more than 2½ volumes of water are separated.

* Amount of water expelled from bladder by alcohol.
† Moist membranes shrink when strewed with salt, or placed in alcohol.
‡ The cause of this is the less affinity of the tissue for alcohol, &c., than for water.

If we lay together, one over the other, two portions of bladder, saturated with solution of salt of sp. g. 1·204, and over the upper one another piece of bladder of equal size, saturated with water, and if we allow them to remain thus, without pressure, we find, after some minutes, when the two pieces saturated with solution of salt are separated, that drops of saline solution appear between them, of which no trace could previously be perceived. If the piece of bladder saturated with water contained 5 volumes of water, and the next piece 3 volumes of saline solution, there must be produced, by the mixture of both, 8 volumes of diluted saline solution, of which each piece of bladder must contain one half, or 4 volumes, if the absorbent power of the portion saturated with the original saline solution were increased by the addition of water in the same ratio as the absorbent power of the portion saturated with water was diminished by the addition of salt. The saline liquid would have given up 1½ volume of saline solution to the other, and would have received from it 2½ volumes of water. In this case, the mixture in the two upper pieces of bladder would occupy the same space which its constituents, water and saline solution, occupied in each singly. But the efflux of the liquid towards the third or lowest piece of bladder saturated with saline solution, proves, that the two upper pieces retain a smaller volume of the mixture newly formed in their pores, than the one piece absorbed of water alone, and the other of saline solution alone. The power of retaining water is diminished by the addition of salt to the bladder saturated with water; liquid is expelled; but by the addition of this water to the bladder moistened with saline solution, the absorbent power of this piece of bladder is increased, not in the same ratio according to which the proportion of salt is diminished, but in a less ratio.

The experiments above described show that the attraction of the porous substances for the water which they have absorbed does not prevent the mixture of this water with other liquids.

The permeability of animal tissues to liquids of every kind, and the miscibility of the absorbed liquids with others which are brought in contact with the tissues, may be demonstrated by the simplest experiments.*

If we moisten one side of a thin membrane with ferrocyanide, of potassium, and the opposite side with chloride of iron in solution, we perceive in the substance of the membrane a spot of Prussian blue immediately deposited. (JOH. MULLER.)

All fluids which, when brought together, suffer a change in their nature or in their properties, exhibit, when only separated by an animal membrane, exactly analogous results; they mix in the pores of the membrane, and the decomposition commences in its substance.

If we tie up one end of a cylindrical glass tube with bladder, and fill it to the height of 3 or 4 inches with water or strong brine, neither the water nor the brine flows out through the pores of the bladder under this slight pressure.

But if we leave the tube containing brine exposed to evaporation in the air, the side of the bladder exposed to the air is soon covered with crystals of salt, which gradually increase, so as to form a thick crust.† It is obvious that the pores of the bladder become fluid with brine; that, on the side exposed to the air, the water evaporates; its place is supplied by fresh brine, and the dissolved salt is deposited at the external minute openings of the pores, in the form of crystals. If the tube be filled originally with dilute saline solution, the crust of salt is not formed on the outer surface of the bladder until the solution in the tube has reached, by evaporation, the maximum of saturation. Before this takes place, we can perceive in the tube, if we set the liquid in motion, two strata, a heavier and a lighter, the latter swimming on the former. When these strata can no longer be observed, the liquid is in every part saturated with salt; and now, by further evaporation, crystals are deposited on the outer surface of the bladder. This last circumstance proves that the amount of salt in the liquid is uniformly distributed from below upwards, from the specifically heavier to the specifically lighter part.

If we immerse the tube closed with bladder, and filled with saline solution, in pure water, the latter acquires the property of precipitating nitrate of silver, even

* Animal tissues are permeable to liquids of every kind, which act on each other in the substance of the tissues.

† Deposition of salt on the outside of bladder from brine on the inside.

when the contact has lasted only the fraction of a second.* The brine filling the open pores of the membrane mixes with the pure water, and the latter acquires a certain quantity of salt.

In like manner, the pure water acquires a saline impregnation, when it is placed in the tube instead of brine, and the outer surface of the bladder is placed in contact with solution of salt.

When the tube, closed with bladder, and filled with brine, is left for a long time with the closed end immersed in pure water, the amount of salt in the latter increases, while that of the brine diminishes, till at last the two liquids, separated by the bladder, contain the same relative proportions of salt and water.

If the liquid in the tube contain, dissolved, other substances which give to it properties different from those of pure water, and if these solutions be miscible with water, the mixture of them with the water takes place exactly as in the case of brine.† This is true of saline solutions of every kind; of bile, milk, urine, serum of blood, syrup, solution of gum, &c., on the one side, and pure water on the other. The concentrated liquid loses, the water or diluted liquid gains, in regard to saline impregnation.

If we fill the tube with water, and place it in a vessel with alcohol, the water becomes charged with alcohol, while the alcohol becomes diluted with water.

There is observed, in these circumstances, that is, when two dissimilar liquids, separated by a membrane, mix together, a phenomenon of a peculiar kind; namely, in most cases a change of volume in both liquids, while the mixture goes on.‡ The one liquid increases in bulk, and rises; the other diminishes in the same degree, and consequently sinks below its original level.

This phenomenon of mixture through a membrane, accompanied with change of volume, has been distinguished by DUTROCHET, under the name of ENDOSMOSIS and EXOSMOSIS; endosmose is the name given when the volume increases—exosmose, when it diminishes.§ Very generally, however, we attach to these terms the idea of the unknown cause or group of causes which, in the given case, produce the change of volume; in the same sense as that in which the term capillary action includes the causes which determine the ascent of liquids in narrow tubes.

In all cases, the increase in volume of the one liquid is exactly equal to the decrease in volume of the other, after making allowance for the contraction which the liquids undergo by simple mixture (as in the case of alcohol and water, oil of vitriol and water, &c.,) as well as by evaporation. The unequal concentration, or the unequal density of the two liquids, has a decided influence on the rapidity with which the change of volume takes place; but this cannot be viewed as the cause of that phenomenon. In most cases the denser liquid increases in volume, in others the reverse occurs.

When, for example, the tube contains brine, and the outer vessel pure water, the brine, that is the denser liquid, increases in volume;‖ but when the tube contains water, and the outer vessel alcohol, the water, that is, the denser liquid, diminishes in volume.

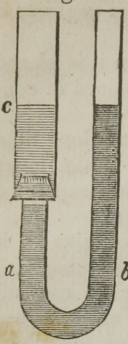
With regard to the mixture of the liquids, the bladder takes a distinct share in the process, inasmuch as it has pores, through which the two liquids are brought in contact.

With reference to the porosity of the bladder, the rapidity of the mixture of the two liquids is directly proportional to the number of particles, which, in a given time, come into contact; it depends also on the surface (the size of the membrane,) and on the specific gravity of the liquids.

The influence of extent of surface on the time required for mixture requires no particular elucidation; that of the unequal specific gravity is rendered evident by the following experiments.¶

* Saline solutions pass very rapidly through bladder.
† The same is true of bile, milk, urine, serum, &c.
‡ Change of volume when two dissimilar liquids mix through a bladder.
§ Endosmosis and Exosmosis.
‖ The change of volume does not depend alone on the relative density of the liquids.
¶ Influence of the unequal density of the two liquids, when the lighter liquid is above the membrane.

Fig. 2.



If the bent tube *a b* (Fig. 2,) one end of which is tied over with bladder, and the other open, be filled with brine colored blue,(1) and if pure water be placed in the tube *c*, there is soon perceived under the bladder a colorless or nearly colorless stratum of liquid, which continues for hours to float in the same place. If the bent tube *a b* be filled with colorless brine, while *c* is filled with pure water colored blue, there is found, after a time, *above* the bladder, a colorless or nearly colorless stratum of liquid.

It appears from this, that an exchange of both liquids goes on through the substance of the bladder; in the first experiment colorless water passes from the tube *c* to the colored brine in the tube *a b;* in the second, colorless brine passes from the tube *a b* to the colored water in the tube *c*.

It is obvious that the brine in the tube *a b*, which is in contact with the bladder, becomes diluted by the addition of water from the tube *c;* but this diluted brine is specifically lighter than the original brine which is below it, and remains therefore floating at its surface.

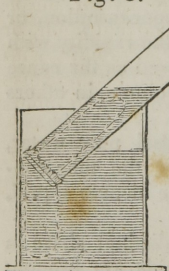
On the other hand, the water in the tube *c*, when mixed with brine from the tube *a b*, becomes heavier than the pure water, and rests, therefore, on the upper surface of the bladder, or that which is turned towards the water.

Hence it follows, that from the moment when these two strata have been formed above and below the bladder, neither concentrated brine nor pure water comes any longer in contact with the bladder.

From the bladder downwards, in the tube *a b* are strata of liquid, containing successively more salt; from the bladder upwards in the tube *c* are strata containing successively more water.

In the beginning of this experiment we observe, that the volume of the water and of the brine changes in both tubes; the liquid in the limb *b* rises from 1 to 2 lines; but as soon as the strata above mentioned have been distinctly formed above and below the bladder, hardly any further rise is perceptible, although the mixture of the liquid proceeds, and the water in *c* becomes constantly more charged with salt, while the brine in *a b* loses salt.

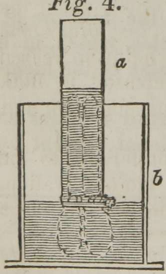
Fig. 3.



If we reverse the positions of the two liquids in the apparatus Fig. 2, or what is simpler, if we close with bladder a tube 1 centimetre ($\frac{4}{10}$ths of an inch) wide, fill it with brine, and immerse the end closed with the bladder in a wider vessel filled with pure water, giving to the tube an inclination of about 45°, we may observe (most distinctly when both liquids contain some fine particles of indigo suspended) in both liquids a continual motion.* We see in the tube (Fig. 3) a current of liquid rising from the bladder in the direction of the arrow, and flowing down again on the opposite side. A similar circulation is observable in the vessel of water.

If the tube *a*, with brine, is about 2 centimetres ($\frac{4}{5}$ths of an inch) wide, and if we support it vertically in the vessel *b* of water, the motion proceeds from the middle, and in both the tube and the vessel we perceive currents in opposite directions. (Fig. 4.)

Fig. 4.



These currents hardly require explanation. To the brine in the tube *a*, pure water passes through the bladder; there is formed above the bladder a mixture containing less salt, and therefore specifically lighter than the brine; this mixture rises, and the denser brine descends to occupy its place.

On the other hand, the pure water receives through the bladder salt, and becomes thereby specifically heavier; while it sinks to the bottom of the vessel, its place is supplied by water containing

(1) For this purpose it is best to take a solution of indigo in sulphuric acid, diluted.

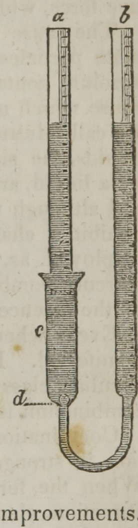
* When the heavier liquid is above the membrane.

less or no salt, and therefore specifically lighter, which again comes in contact with the bladder. As long as the motions just described are perceptible, we observe a constant increase in the volume of the brine in the tube *a* (Fig. 4,) or a diminution in the volume of the pure water in the vessel *b*. When the motions cease, the rise of liquid in the tube is arrested, and when this takes place, the two liquids are found to possess almost exactly the same specific gravity.

When the two strata of liquid on either side of the bladder are little different in composition (as soon comes to pass in the experiment (Fig. 2) where the saline contents of the liquid which fills the pores of the bladder can hardly vary from that of the next stratum,) the mixture of the liquids takes place, but without further change of volume. But when an exchange of the mixtures on the opposite sides of the bladder can occur in consequence of their different specific gravity, and when a continued difference between the strata on opposite sides of the bladder is thus determined, then, so long as (in the case of brine and water, for example) one side of the bladder is in contact with a concentrated, the other with a more diluted solution, the change of volume in the two liquids continues.

As appears from these experiments, the change of volume depends on a difference in the character of the two liquids which are connected through the bladder; and the time during which change of volume occurs is in direct proportion to the time during which this difference in character subsists. The greater the difference in character and composition between the liquids, and the more rapidly this difference is renewed by the exchange between the strata in contact with the opposite sides of the bladder, the more rapidly does the one liquid increase, and the other diminish in volume.

Fig. 5.



The following apparatus is very convenient for measuring the change in volume, caused by the mixture of two liquids separated by a membrane.*

The tubes *a* and *b*, (Fig. 5) are of equal width, and are best taken from the same tube; *a* is closed with bladder, and filled up to a certain point with the liquid whose increase in volume is to be determined. It is then fitted by means of a good cork into the wider tube *c*, which contains distilled water, care being taken to exclude all air bubbles. At *d* lies a small lead drop, which acts as a valve in shutting the opening of the capillary tube connecting *c* with *b*. Pure water is now poured into *b*, and in order to keep in equilibrium the lead drop at *d*, rather more water is added than exactly suffices to bring the liquids to the same level in both tubes.

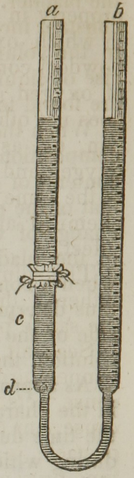
The liquid in *a* increases in volume, and the height to which it rises may be read off by means of any division into equal parts by measure; the level of the liquid in *b* sinks in an equal ratio. If we keep the liquid in *b*, by the addition of fresh water, at the original level, and if we ascertain the weight of the added water, by pouring it out of a dropping bottle, and determining the loss of weight in the dropping bottle, we learn, at the same time, the weight and the volume of the water which has risen from *c* into *a*. This apparatus admits, of course, of a number of variations and improvements. I have employed it to determine the relation between brine and water, under the circumstances just described. It appeared, among other things, that when the tube *a* is filled with saturated solution of sea salt, the volume of the liquid increased by nearly one half; that is, 200 volumes of such a solution increased to 300. These determinations are, however, not the object of the present investigation, and therefore I pass them over entirely.

The following arrangement, (Fig. 6) will probably be found preferable to the one just described, in many cases. Its construction depends on the observation, that for the phenomenon itself, and for the result of the experiment, it is entirely a

and after adding subacetate of lead as long as sulphoindigotate and sulphate of lead are precipitated, to separate the precipitate by filtration and dry up the filtered liquid in the water bath. A mere trace of the blue residue suffices to color blue large masses of liquid.

* The change in volume may be measured.

Fig. 6.



matter of indifference whether the tube be closed with a single, double, or treble layer of bladder.([1]) For experiments on very thin membranes which are permeable to liquids under a very low pressure, the apparatus (Fig. 5) is obviously better adapted. For the explanation of the phenomenon we have to distinguish—

1. The mixture of different liquids.
2. The change in their volume.

As to the mixture of two liquids of dissimilar nature and characters, this always depends on a chemical attraction.* In a mixture of alcohol and water, or of brine and water, there is in every part the same proportion of particles of alcohol and water, or of salt and water. If in the former, the lighter particles of alcohol lying at the bottom of the vessel were not retained, in the place and arrangement which they occupy, by the surrounding particles of water, they would undoubtedly rise towards the surface. In like manner, the particles of salt in the brine are sustained and prevented from sinking by the lighter particles of water which surround them.

Without an attraction, which all the particles of alcohol or of salt must have towards all the particles of water, or all the particles of water must have for all those of salt and alcohol, a uniform mixture cannot even be conceived. If but one particle of alcohol were less powerfully attracted than the surrounding particles, it would rise to the surface; and in like manner, the particles of salt would, in consequence of their greater specific gravity, gradually occupy the bottom of the vessel, were it not that a cause prevents them from rising or falling; and this cause can be nothing but an attractive force, which retains them in the place where they happen to be.

The cause which effects a change in the place or in the properties of the ultimate particles or atoms of dissimilar substances, when these particles are in absolute contact, or at infinitely small distances from each other, as well as the cause which manifests itself as a resistance to such changes of place or properties, we call CHEMICAL ATTRACTION;† and in this sense the mixture of two dissimilar liquids, the simple moistening of a solid body, the penetration and swelling of it by a liquid, are effects in which chemical affinity or attraction has a decided share; and although we are accustomed to limit the notion of affinity to such cases as exhibit a change perceptible to our senses, in the properties of the substances employed, as, for example, when sulphuric acid and lime, or sulphuric acid and mercury combine together, this limitation arises from the imperfect apprehension of the essence of a natural force.

Every where, when two dissimilar bodies come in contact, chemical affinity is manifested. It is a universal property of matter, and by no means belongs to a peculiar class of atoms, or to a peculiar arrangement of these. But chemical combination is not, in all cases, the result of contact.

Combination is only one of the effects of affinity, and occurs when the attraction is stronger than all the obstacles which are opposed to its manifestation.‡ When the forces or causes, which oppose chemical combination, heat, cohesive attraction, electric attraction or whatever they may be called, preponderate, then chemical combination does not take place; and effects of another kind are manifested.

Melted silver in a crucible, surrounded with red hot coals, in a place, therefore, where we should hardly anticipate the presence of free oxygen, absorbs as much

([1]) In these experiments membranes of all kinds may be used. With the thinner membranes, such as the bladder of the calf and the pig, the experiments are more rapidly completed than with the thicker, such as the gall-bladder and urinary bladder of the ox. The peritoneum of the ox and calf is preferable to all others. The tube c is tied with bladder under water.

* Causes of the mixture of dissimilar liquids.
† Chemical affinity is the chief cause of mixture.
‡ Affinity is everywhere active between bodies in contact.

as ten or twelve times its volume of that gas. Metallic platinum exhibits the same property in a far higher degree; for from the atmospheric air, a gaseous mixture in which oxygen forms only the fifth part, that metal (in the form of a black powder) condenses on its surface, at the ordinary temperature, an enormous quantity of oxygen gas (without any nitrogen,) and acquires thereby properties, which it does not otherwise possess.(1) And when oxide of chromium, fragments of porcelain, or asbestus, at high temperatures, effect the combination of two gases, oxygen and hydrogen, or oxygen and sulphurous acid, which gases do not combine at the same temperature, unless when in contact with these solid bodies, it is to the chemical attraction or affinity of these solid bodies that we must ascribe this effect.

The solution of a salt in water is an effect of affinity, and yet no one property, either of the salt or of the solvent, is thereby altered, except only the cohesion of the saline particles.

Sea salt, the crystals of which are usually anhydrous, takes up, at very low temperatures, 38 per cent. of water of crystallization;* not because any new cause acts which increases its affinity for the particles of water (for cold is no cause, but the absence of a cause,) but because the higher temperature acted as an obstacle, opposing their chemical combination. The force of affinity is all the time present and undiminished.

When we add alcohol to the solution of a salt in water, we observe, that now the salt separates from the liquid in the form of crystals, doubtless only because, by the addition of another chemical force, the amount of attraction between the particles of the salt and those of the water has been altered.

The aqueous particles, which were combined with the saline particles, manifest an attraction for the particles of alcohol; and as the latter have no affinity, or only a very feeble affinity, for those of the salt, the attraction of the saline particles for each other is strengthened. This attraction was present in equal force before the addition of the alcohol, but the resistance which opposed their union (the chemical attraction for them of the aqueous particles) was more powerful.† The alcohol was not the cause of the separation. The cause of the separation of the salt from the liquid, its crystallization, is at all times the force of cohesion; and by the alcohol the cause which opposed its manifestation was removed.

The affinity of potash for sulphuric acid is known, and sulphate of potash readily dissolves in water. If we add, to a saturated solution of that salt, an equal volume of aqua potassæ of sp. g. 1.4, there is immediately formed a crystalline precipitate of sulphate of potash, and the sulphuric acid is separated in this form from the water.

In these cases the chemical effect (the separation) depends on the presence of a certain quantity of the liquid which is added (such as aqua potassæ, alcohol, &c.,) but in many other cases there is required only a slight alteration in the quality of the solvent to effect separations of this kind.

When hydrochloric acid is added to a solution of ferrocyanide of potassium, ferrocyanic acid is set free, and remains dissolved in the liquid. If now the vapor of boiling ether be passed through the mixture, there occurs, after a few moments, a complete separation. The whole of the ferrocyanic acid is deposited from the liquid in the form of white or bluish-white crystalline scales, which generally appear in such quantity as to render the whole mass semisolid. In proportion as the vapor of ether is dissolved by the water, the latter fluid loses entirely its solvent power (its affinity) for the ferrocyanic acid. The coagulation of albumen by ether depends on a similar cause.

The capacity of solids to become moistened by liquids, and, in short, all

(1) According to Dœbereiner, platinum black condenses 252 times its volume of oxygen. Its effect in oxidizing alcohol, pyroxilic spirit, &c., is familiar to every chemist.—W. G.

* Crystallization of sea salt.

† Precipitation of salt from its solution by alcohol; of sulphate of potash by caustic potash; of ferocyanic acid by ether; of suspended mud by alum.

phenomena connected with chemical affinity, are affected, altered, increased, or destroyed by causes quite analogous.

After heavy rains, the water of many rivers becomes turbid and opaque from the presence of a fine clay. These suspended particles of clay are so fine as to pass through the finest filters; and their adhesion to the water is so great, that such water does not clear after standing for weeks. The water of the Yellow River, in China, possesses, during the greater part of the year, this character; and from the French missionaries, we know that alum is universally employed in Pekin to clear it. In fact, if a crystal of alum be held in such a water only for a few seconds, we observe the sediment separating in large thick flocculent masses, the water becomes transparent, and hardly a trace of dissolved alum is to be detected by the most delicate re-agents. Chemistry is acquainted with a number of similar means for causing the separation from liquids of suspended precipitates.

In these cases we see, that by an alteration of the quality of the water, produced by what we call mere mixture with a foreign body, its power of combining with others is destroyed or weakened.

It is well known that the force with which, in a solution, the particles of the liquid and those of the dissolved body attract each other, is very unequal in different cases;* and in this point of view the action of many solid bodies on saline solutions is very remarkable; inasmuch as it is thereby demonstrated, that the molecular force, which determines the phenomena of cohesion, and the moistening of solid bodies by liquids appears to be identical with chemical affinity, since chemical compounds can be decomposed by means of it. Professor GRAHAM has shown that common charcoal, deprived by acids of all soluble ingredients, completely removes the metallic salts or oxides from solutions of salts of lead, tartar emetic, ammoniated oxide of copper, chloride of silver in ammonia, and oxide of zinc in ammonia; while other solutions, such as that of sea salt, suffer no such change. A bleaching solution of hypochlorite of soda loses entirely its bleaching properties by agitation with charcoal; and iodine can be removed by the same means from its solution in iodide of potassium. Every one is familiar with the action of finely-divided platinum, with that of silver on the deutoxide of hydrogen; as well as with that of charcoal on dissolved organic matters, coloring matters, &c.; and freshly-precipitated sulphuret of lead, sulphuret of copper, and hydrate of alumina, resemble the latter in their action. Many organic substances, such as woody fibre and others, act on dissolved matters, such as salts of alumina or of oxide of tin, just as charcoal does; and we know that the application of mordants in dyeing, and dyeing itself depend on this very property. The adhesion of the solid coloring matter to the cloth which is died with it is the result of a chemical affinity so feeble, that we hardly venture to give the molecular force that name in this case. From a piece of woollen cloth dyed with indigo, the indigo is completely separated, by mere beating, continued for some time, with a wooden hammer, so that the wool is at last left white.

The surface of the solid body exerts, as these facts prove, a very unequal attraction on the molecules, which come in contact with it.

Researches on capillary attraction have shown that, with one and the same liquid, water, for example, the substance of the solid body has no influence on the height to which the liquid rises on it. On slices of box-wood, clay-slate, or glass, the rise of the liquid above the surface of the water is the same exactly as in the case of a plate of brass. (HAGEN.) In the case of other liquids, the particles of which are entirely homogeneous, the same law may be assumed in theory; but with such liquids as contain foreign bodies in solution, a change in the capillary attraction must be produced by the presence of these bodies, because by them the cohesion of the liquid is altered; and, perhaps, still more because the liquid ceases to be homogeneous, when the attracting wall has a stronger affinity for the particles of the dissolved body than for those of the solvent.

From what has been stated, it appears, that the mixture of two liquids is the result of a chemical attraction; for how otherwise could chemical compounds,

*Action of solids on dissolved matters.

such as the solution of a salt in water, be decomposed, or a chemical attraction be overcome, by its means ?

Two liquids of different chemical properties, which are miscible together, and which, therefore, have a chemical attraction for each other, mix readily at all points where they come in contact.* By motion, shaking, &c., the number of points of contact within a given time is increased, and the formation of a uniform mixture is thus accelerated.

If these liquids be of equal, or still better, of unequal, specific gravity, they may be, with the aid of some precaution, stratified one above the other. This is, in point of time, the most unfavorable case for the mixture, since proportionally small surfaces come in contact. But wherever they do come in contact, it is, after a very short time, impossible to detect any limit between them.

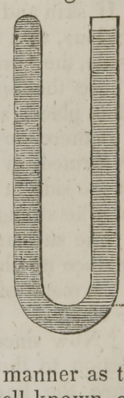
In a cylindrical vessel containing solution of salt, the saline particles at the surface are attracted and sustained by aqueous particles, which exist at the sides of the saline particles and from the surface downwards. From the surface upwards, the attracting aqueous particles are absent.

Now it is evident that when the surface is brought in contact with pure water, a new attraction is added to those previously existing, which acts in an opposite direction, namely, the attraction of the aqueous particles floating on the surface for the saline particles, and vice versa (the attraction of the saline particles to the aqueous particles in contact with them.)

At the place where pure water and brine are in contact, there is thus formed a uniform mixture of the two, which upwards is in contact with pure water, downwards with brine.

Among these three strata, of which the upper contains no salt, the lower less water, a new division takes place ; the more strongly saline stratum loses salt, the pure water becomes saline, and in this way salt and water are at last uniformly distributed throughout the liquid.

Fig. 7.



If we fill one limb of the tube (Fig. 7,) as far as *a*, with brine colored blue, and the other limb with water, we find, in the course of a few days, the water colored blue, and the proportion of salt in both limbs equal.† It has been mentioned at p. 15, that, in a tube closed with bladder, filled with diluted solution of salt, and exposed to evaporation, the salt is not deposited in crystals on the outer surface of the bladder till the whole liquid in the tube has reached, in consequence of evaporation the maximum of saturation. The water evaporates from the exterior of the bladder, but no salt is deposited, as long as a liquid exists within which can still dissolve salt ; and in this way the heavier saline particles are distributed towards the interior, and upwards through the whole liquid, or, what amounts to the same, the lighter aqueous particles, which can still dissolve salt, are distributed downwards towards the external surface of the bladder.

This distribution of salt through water takes place in the same manner as the conversion of bar iron into steel.‡ Rods of malleable iron, as is well known, are kept ignited between strata of charcoal, whereby the surface of the iron in contact with the charcoal takes up carbon, and becomes a carburet of iron. The stratum of iron lying next under this surface, which has the same attraction for carbon, acquires carbon from the superficial stratum immediately in contact with it, and in its turn gives carbon to the stratum below itself. This process, if continued long enough, has no limit till all the strata of particles have acquired an equal proportion of carbon, that is, till they are all saturated with it. A piece of red-hot malleable iron, if kept a few moments in contact with pig iron (a carburet of iron) is found to be already converted into steel at the points of contact. The mixture of liquids depends on the same principle ; and we may suppose that their distri-

* Laws of mixture of two liquids.

† Experiment showing the uniform mixture of two liquids.

‡ The distribution of salt through water, resembles the conversion of iron into steel by cementation.

bution is mutual, because their particles may move in all directions, and that consequently saline particles move towards aqueous particles, as well as aqueous towards saline particles, in virtue of their mutual attraction.

From a solution of sulphate of copper in ammonia, placed in a tall glass cylinder, there is gradually separated, if we pour a stratum of alcohol on the surface, and if we prevent the formation of a coherent crust which impedes the contact of the liquids, the whole of the ammoniated sulphate of copper, while the deep blue solution becomes colorless, because by the distribution of the alcohol through the solution a mixture is formed, in which the salt is insoluble.

The rapidity of mixture of two liquids depends on the degree of their chemical affinity;* and the unequal mobility of the particles of one or the other liquid has a favorable or unfavorable influence on the result.

When the one liquid is heavier than the other, and of tough, viscid consistence, a much longer time elapses before the ingredients of the tougher or heavier liquid reach the surface from the bottom of the vessel; and in this case the greater density and the less mobility of the particles are obstacles to the mixture.

On the other hand, if the heavier or more viscid liquid be placed above the lighter, the mixture takes place rapidly; at the points where both liquids are in contact is produced a mixture, which, being heavier, descends, whereby the heavier liquid above is continually brought in contact with new surfaces of liquid.

The very same phenomenon is observed in solution.† A fragment of sugar, when covered with water at the bottom of a narrow cylinder, dissolves very slowly, while, if suspended just below the surface, it rapidly disappears. In the former case there is produced round the sugar a thick syrupy viscid solution, which protects the undissolved part of the sugar for a long time from contact with the water; in the latter there is formed at the surface a solution, which descends in striæ, and gradually disappears, while by the change of place thus induced, new portions of water are constantly brought in contact with the undissolved sugar, and are thus enabled to exert their solvent powers.

If skin and membranes consist of a cohering system of very narrow tubes, it is obvious, that when two dissimilar, but miscible liquids are separated by such a tissue, the pores of the tissue will fill with each of the two liquids. In all situations, where the liquids came in contact in the substance of the membrane, a mixtnre takes place, and this mixture is extended equally towards both sides.

If there be brine on one side of the bladder, and water on the other, there must be formed, in the middle, or at some point of the bladder, a diluted brine, which on the side in contact with the water yields salt to that water, while on the opposite side the strong brine mixes with the diluted brine in the bladder.

The substance of the bladder has no influence on this mixture, because it can produce no change of place on the part of the saline or aqueous particles, for this is the result of the chemical affinity acting between the particles of salt and those of water.

‡ Now since the rapidity of the mixture of two liquids stands in a direct proportion to the amount of surfaces coming into contact within a given time, and since the liquids, separated by a bladder, can only come in contact through its pores, while the number of points of contact is diminished by the presence of the non-porous parts of the bladder, it follows, that, exclusive of all other effects, the time required for mixture must be lengthened by the interposition of a bladder. In the absence of the bladder, the mixture would take place exactly as when it is present, except in regard to time.

When the heavier brine is under, the water above the bladder, the two liquids mix more slowly than without the bladder.

But since a bladder, inasmuch as a feeble hydrostatical pressure is not propagated through its pores, allows us to place a heavier liquid above a lighter, and to retain

* Mixture is influenced by chemical affinity, by unequal mobility, and by unequal density in the liquids.

† Effect of position on the solution of a solid.

‡ Rapidity of mixture.

it in that position; this circumstance has the effect of promoting mixture, the ultimate cause of which is, not the bladder, but the specific gravity of the liquid.* The bladder is a means of enabling the specific gravity to influence mixture. The foregoing remarks appear to me sufficiently to elucidate the share taken by the bladder in the mixture of two dissimilar liquids placed on opposite sides of it.

With respect to the change of volume in the two liquids which become mixed through the bladders, we must consider, that the moistening or absorbent power of a solid body, as well as the power of a liquid to moisten other bodies, is the result of a chemical action.† Liquids of different properties, or of different chemical characters, are attracted with unequal degrees of force by solid bodies, and exert towards them unequal degrees of attraction, and if we alter even in a system of capillary tubes, filled to a certain height with a liquid, the chemical nature of that liquid, we change thereby the height at which the liquid stands. In an animal tissue saturated with water, the water is prevented from flowing out by the mutual attraction, and by the capillary force, but if the attraction of the organic parietes for water be diminished by the addition of alcohol or of salt to the water, a part of it flows out. To this must be added, that the water absorbed by an animal texture when it enters the capillary tubes, exerts, in virtue of its attraction for the tubes, a certain pressure, by which the vessels are swoln and enlarged. The particles of liquid in these tubes undergo a counter-pressure from the elastic parietes, by which pressure, when the attraction of the liquid particles for the solids is diminished by any new cause, the amount of expelled fluid is increased.

The organic parietes of the tubes, saturated with water, are affected by alcohol just as a salt is when dissolved in water. On the addition of alcohol, or of another liquid, the water separates from the salt, or from the parietes, or the parietes separate from the water.

If the animal tissue possessed as great an attraction for the newly-formed mixture as for the water alone, the volume of the liquid would not change. The mixture would take place, but no water would flow out.

A bladder, saturated with water, when brought in contact with alcohol, shrinks together, a part of the water separates from the animal matter, but there always remains in the bladder a certain amount of water, corresponding to its attraction for the bladder and for the alcohol; just as the solutions of many salts which have a strong attraction for water (such as a metaphosphate and acid phosphate of soda,) and are insoluble in alcohol, are separated by the addition of alcohol into two strata of liquid, the heavier of which is a more concentrated solution of the salt in water, containing a little alcohol, while the other, the lighter, is an aqueous liquid containing much alcohol. The alcohol and the salt divide between them the water of the solution.

When we add, to a mixture of equal parts of acetone and water, a certain quantity of dry fragments of chloride of calcium, the first fragments which are added deliquiesce and dissolve entirely in the mixture.‡ But if we go on adding the salt, a separation soon occurs, two strata of liquid are formed, of which the upper contains acetone and water, the other is an aqueous solution of the chloride with a little acetone. If we add still more of the chloride, water is abstracted from the acetone of the upper stratum, and when a proper quantity has been added, the acetone retains no trace of water.

If we suppose, that of the two originally formed strata of liquid, one of them, namely that which sinks and contains chloride of calcium dissolved, is in contact with a current of dry air, the water of this solution will evaporate, the solution will thus become stronger, and in consequence of its increased concentration will be able to remove a new portion of water from the mixture of acetone and water above it; and this will continue till the acetone is entirely deprived of water.

If in the place of the chloride of calcium we put a bladder, and, in place of the acetone and water, diluted alcohol, we have the finest example of the unequal

* In certain circumstances, the interposition of a membrane accelerates mixture.

† Change of volume in liquids which mix through a membrane is the result of chemical affinity modifying capillary attraction.

‡ Action of chloride of calcium on a mixture of acetone and water.

attraction which the animal tissue exerts on the two ingredients of the mixed liquid.*

It is known from the experiments of SOEMMERING, that spirits of a certain strength, inclosed in a bladder, which is opposed to the air, lose by evaporation only water, and that at last anhydrous, or nearly anhydrous (absolute) alcohol is left in the bladder. When strong spirits of wine are used, the bladder remains dry externally; when weaker spirits are employed, it becomes moist, and alcohol evaporates with the water. In virtue of the unequal affinity of the bladder for alcohol and for water, a complete separation is here effected. The water of the mixture is absorbed and evaporates from the outside of the bladder; the alcohol remains in the bladder. As yet, we are acquainted with no substance which can replace the bladder in this operation; and indeed, the affinity of the gelatinous tissues (membranes, &c.) for water must exceed that of all other animal tissues, since a rise of temperature, of a few degrees only, suffices to enable water to dissolve that tissue perfectly into a jelly.

MEGNUS assumes, "that the particles of every solution, for example, of a salt in water, adhere more strongly to each other than do those of the solvent, for example, of water; consequently, the solution would be less fluid, and pass with greater difficulty through very narrow openings, than water, if we take for granted that the parietes of the openings act alike towards both. It would follow from this, that, the more concentrated a solution, the less easily would it pass through the same openings."†

"Let us now try," pursues MAGNUS, "with the aid of these assumptions, (which, as appears from the experiment Fig. 1, are perfectly accurate and demonstrable for many saline solutions, although there are, according to the researches of POISEULLE, a number of exceptions(1)) to explain the phenomena of ENDOSMOSIS."

"Both the brine and the water will penetrate into the pores of the bladder, and brine will pass from the pores to the water, as well as water to the brine, in virtue of their mutual attraction, till a complete equilibrium is established. Further, since the force which attracts the water to the brine is exactly the same as that which attracts the brine to the water, as much water as brine would pass through the bladder, if both liquids could pass with equal facility through the pores. Since, however, this is not the case, unequal forces are required to urge the two liquids through the pores; or with equal forces, unequal quantities of the two pass through in equal times. There is consequently added more of that which passes most easily, the water to the brine, than of the latter to the water, and the level of both liquids must change, if no other force oppose this change."(2)

According to this theory, brine and water exist in the pores of the bladder in a state of motion, and the chemical affinity, which the particles of the brine have for the particles of the pure water, and conversely, which the particles of water have for those of salt, is considered as the cause of this motion. The unequal velocity, which makes more water flow in a given time to the brine than brine or salt to the pure water, is, according to MAGNUS, determined by the unequal resistance which the substance of the bladder opposes to the passage of the two liquids.

Now, however narrow the tubes may be, in which molecules are set in motion by an external force, it may always be assumed, that that part of the molecules, which is immediately in contact with the wall of the tube, either is not in motion, or possesses only a small velocity, and the velocity of efflux must be a function of the cohesion, and at all events not dependent on the wall of the tube.

If now the efflux of the water on one side of the bladder is produced by the attraction of the saline particles for the water, and the efflux of the brine on the other side is produced by the attraction of the aqueous particles for the saline

(1) Ann. de Ch. et de Phys. 3rd series, xxi. pp. 84 *et seq.*
(2) Poggendorff's Annales, x. p. 164.

* Effect of evaporation through a bladder in concentrated alcohol.
† Views of Magnus on Endosmosis.

particles, it is impossible to explain how water and brine can move in the same tube with unequal velocity in opposite directions; the two liquids being supposed to have a mutual attraction, that is, to be miscible. This attraction must act within the tube just as well without; and we might, therefore, suppose, that when the two liquids have become mixed, the mixture could only move in one direction with a medium velocity.

Assuming that a mixture is formed in the open orifices of the pores or tubes, or in any part of them, it is difficult to see, why saline particles should not pass from one side to the water, or aqueous particles to the saline ones in the bladder, since the mutual attraction must be regarded as equal on both sides. The chemical affinity of the two liquids does not explain the efflux.

If we suppose, that in certain pores only brine, in others only pure water moves, the phenomenon ought not to occur when all the pores are filled with water or with brine, or when the tube is tied with a double, treble, or fourfold, bladder. But the properties of bladder are seen in the finest as well as thickest membranes, and one, two, or three layers make no difference in the ultimate result.(1)

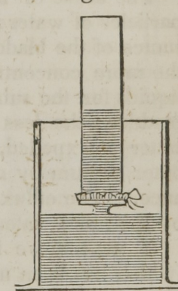
The kind of influence which the nature of the partition, or its attraction for the liquids in contact with it, exerts on the phenomenon, is seen by comparing the action of an animal membrane with that of a thin sheet of caoutchouc.*

In a tube, closed with bladder, which is filled with alcohol, and immersed in pure water, the volume of alcohol is increased; more water passes to the alcohol than alcohol to the water.†

If, without making any other change in the experiment, the tube be closed with a thin sheet of caoutchouc, the volume of the alcohol now diminishes while that of the water increases.

Here, all the circumstances of the mixture of the two liquids have remained the same except the nature of the partition, which makes the difference in the result.

Fig. 8.



When we fill with brine a tube, closed with bladder, (Fig. 8,) and place it in a vessel of water, so that the bladder and water only communicate by a single drop, the liquid in the tube increases in bulk, and rises in the tube, as if the bladder had been immersed in the water; but the drop becomes gradually smaller, till after an hour or two, a complete separation takes place, and the drop tears itself away from the water.(2)

If the cause of the change of volume in this experiment were the unequal resistance which the bladder opposes to the passage of the two liquids with equal attraction (equal force) on both sides, the phenomenon just described would be inexplicable; for a resistance can no doubt impede, but is not capable of producing motion. But we see, that the water in this experiment is raised to a higher level, and moreover, the tearing asunder of the drop can only be the effect of a powerful attraction, residing in the substance of the bladder.

(1) With respect to the theory, that, when a saline solution is mixed with pure water, if the two liquids are separated by a membrane, particles of salt alone pass through the pores of the bladder to the water, and particles of water alone to the brine, the following experiments may throw some light on the question. For the sake of greater accuracy, the results were determined by weighing. The apparatus, Fig. 3, was used. The tube contained 8·67 grammes of saturated brine, in which were 2·284 grammes of salt and 6·38 of water. After 24 hours it had gained 1·79 grammes in weight, and it now contained only 0·941 grammes of salt. It had therefore lost 1·343 grammes of salt, and gained 3·13 of water. According to the above theory, 1 atom of salt and

[2] If we pour into a tube, ¼ of an inch wide, and closed with bladder, as much mercury as covers the surface of the bladder, then fill it with brine, and place it in pure water, the volume of the liquid in the tube increases exactly as if the mercury were not there.

* The nature of the membrane has an important influence.
† Experiment with bladder, and with caoutchouc.

If the moistening of solid bodies by liquids be the effect of a chemical attraction the force of which is different in dissimilar liquids, it follows that, when a porous body is saturated with a liquid, and brought in contact with a second liquid, which has a stronger attraction for its substance than the first has, then the liquid must be displaced from the pores by the second, even in the absense of hydrostatic pressure, and this, whether the two liquids be miscible or not.*

We may suppose that the attraction of the second liquid, of more powerful affinity, which displaces the other, is equal to the pressure of the column of mercury required to force the latter through the porous substance.

If we tie over one end of a cylindrical tube with a very thin membrane, saturated with concentrated brine by steeping 24 hours, and if we dry the outer surface of the membrane carefully with bibulous paper, and now pour a few drops of pure water into the tube so as just to cover the inner surface of the membrane, the outer surface is seen in a few moments to be covered with minute drops of brine; that is, brine flows out of the pores of the bladder.

A thick ox-bladder, saturated with oil, exhibits the same phenomenon in contact with water. The oil is expelled from the pores of the bladder by the water, which occupies its place.

When the bladder is brought in contact with pure water, it takes up a certain quantity of that liquid. If its pores are previously filled with brine, and if we cover one side of it with pure water, the water mixes with the brine in the pores of the bladder; and on the side next the water there is formed a diluted brine, which, being in contact with a stratum of pure water, mixes with it, and in this way the successive strata of water receive, from the bladder outwards, a certain quantity of salt.

In the interior of the bladder, there are formed in like manner, towards the outer surface, mixtures of unequal saline strength. If we suppose the bladder to consist of several strata, all these strata receive, from the surface in contact with the water, a certain quantity of water; the outer stratum, in contact with the air, receives least, and is the most highly charged with salt.

The cause of mixture is the cheminal affinity of the salt for the newly-added particles of water; this affinity is equal on both sides, but the attraction of the substance of the bladder is stronger for the more aqueous or less saline liquid, than for the more concentrated. In consequence of this difference in the attraction of the liquids for the substance of the bladder, a part of the mixture is displaced from the bladder; the less saline liquid takes the place of the more saline; a part of the latter is expelled, and, with it, a part of that water which has been added to the outer stratum by mixture. Brine and water flow out in the direction of least resistance. The efflux towards the side on which the pure water was poured is prevented by the more watery liquid for the substance of the bladder.

If we remove from the outer surface of the bladder the displaced saline liquid (which has been mixed with some water,) and put stronger brine in its place, and if on the opposite side we remove the very diluted solution, replacing it by a still more diluted one, the same process is repeated. There arises a permanent difference, and a state of mixture and efflux continues till the liquids on the opposite surfaces of the bladder have the same, or very nearly the same, composition.

If we suppose, that the two liquids moisten the bladder unequally, it follows,

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* One liquid expels another from a membrane.

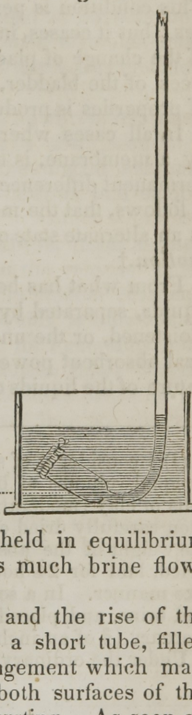
15 atoms of water must have moved past each other; but this is impossible, since 1 atom of salt requires 18 atoms of water for solution, (10 parts of salt to 27 of water.) The weight of the pure water in the outer vessel was 19·26 grammes; consequently, the weight of the brine was to that of the pure water as 1 : 2·22. In another experiment, in which the weight of the brine in the tube was to that of the water outside, as 1 : 7·98; the tube gained 0·822 grammes in weight; the liquid in the tube contained at first 0·947 grammes of salt; and 24 hours after, 0·148 grammes: hence, 1·621 grammes of water had entered, while 0·799 grammes of salt had passed out. For 1 atom of salt, which passed from the tube with brine to the vessel with water, there passed from the latter to the former rather more than 13 atoms of water; (for 58·6 parts, or 1 atom of salt, 118 parts of water.)

that in addition to the chemical attraction which the dissimilar particles of the liquids have for each other, a new cause, namely, the strong attraction of one of them for the substance of the partition, is introduced, which accelerates their motion or passage, and must have this effect, that one of them flows out in larger quantity, in the same time, than the other.

The experiments (Fig. 3) elucidate this process, and show besides, that the exchange of the two liquids on both sides of the bladder is essentially determined by their unequal specific gravities.* As long as the difference in their composition (which may here be measured by the specific gravity) is very great, the change of volume (increase of one and decrease of the other) takes place rapidly; but at last, when this difference becomes very small, the liquids mix without further visible change of volume, obviously, because the attraction of the bladder to the mixtures on the opposite sides does not perceptibly differ, although the specific gravities are still somewhat unequal.

In the ultimate result, the action of dissimilar liquids on the substance of animal tissues, in consequence of which their mixture is attended with a change of volume, appears to be equivalent to a mechanical pressure, which is stronger from one side than from the other.†

Fig. 9.



‡ If the tube (Fig. 9,) which is closed with bladder at its wide opening, be filled with brine to the mark *a*, if so much mercury be then poured into the narrow vertical part as by its pressure to cause brine to begin to flow out in fine drops from the pores of the bladder, and if now, after removing so much of the mercury that the efflux is no longer visible, we place the apparatus in a vessel with pure water, colored blue, as in the figure, the mercury does not change its level; and when, after one or two hours, we carefully remove the tube from the water, we find that in the upper part of the wide end of the tube, which contained colorless brine, a dark blue stratum has been formed, which floats on a colorless liquid. After a longer time, the blue color spreads gradually downwards, till at last the brine acquires a uniform blue tint.

It will readily be perceived, that the two liquids here mix, as if no pressure had been applied to the brine, for a mechanical pressure exerts no influence on the mixture; but, in consequence of the pressure, the mixture takes place without change of volume. The mechanical pressure which the water, in virtue of its stronger affinity for the bladder, exerts on the brine in the pores of the bladder, is held in equilibrium by the column of mercury, and the result is that exactly as much brine flows out as water flows in.

§ Let us suppose the column of mercury to be removed, and the rise of the brine in the narrow tube is explained at once. If we close a short tube, filled with alcohol or brine, with bladder at both ends (an arrangement which may represent a cell,) and suspend it in a vessel of pure water, both surfaces of the bladder become convex outwards; they swell, but without bursting. As soon as the pressure, gradually increasing by the influx of water into the interior of the tube, is sufficient to keep in equilibrium the affinity of the water for the bladder, and consequently its further influx, the exchange goes on, for the future, without change of volume.

Most porous bodies exhibit the phenomena described in the preceding pages, if their pores are so minute that a feeble hydrostatic pressure is not propagated

* Mixture is essentially determined by the unequal density of the liquids.
† The action of two liquids on animal tissues equivalent to a mechanical pressure, unequal on opposite sides.
‡ Experiment to show that an external pressure prevents change of volume.
§ Additional experiment.

through them.* These phenomena may be produced with clay cells (¹) (such as are used for galvanic apparatus;) with the lining membrane of the pods of peas and beans; with the fine inner bark of trees; with the skin of grapes, of potatoes, of apples; with the inner membrane of the capsules of bladder senna, &c.; but animal tissues surpass all others in efficacy. Besides their unequal affinity, they have an unequal absorbent power for dissimilar liquids, by which their action in causing change of volume during mixture is strengthened.

When a tube, closed with bladder, and filled with water, is immersed in alcohol or brine, there is produced at all points, where the brine or the alcohol comes in contact with bladder saturated with water, a change in the properties of the bladder.† When, in the open pores, the alcohol or brine mixes with the water already there, the absorbent power of the bladder for the water is diminished; a smaller volume of the mixture is retained than of pure water; that is to say, water flows out in the direction of the alcohol or brine. This efflux is accompanied by a change in the volume of the substance of the bladder, for that side of it which is towards the alcohol or the brine contracts or shrinks.

The opposite surfaces of an animal membrane, in contact with dissimilar liquids, for which they have unequal absorbent power, are in an unequal state of contraction. This condition is permanent, as long as the liquids do not change in their properties; but it ceases, in consequence of mixture, and is again restored, when, by means of the change of place in both the liquids which are in contact with the opposite surfaces of the bladder, the original or any other permanent inequality or difference of properties is produced.

In all cases where a permanent change in the volume of two liquids, separated by a membrane, is observed during their mixture, it is always accompanied by a permanent difference in the nature or properties of the two liquids; and from this it follows, that the molecules of the animal membrane must be, during the mixture, in an alternate state of contraction and swelling, or dilatation; that is, *in a continual motion.*‡

From what has been stated, it appears that the change of volume of two miscible liquids, separated by a membrane, is determined by the unequal capacity of being moistened, or the unequal attraction of the membrane for these liquids. The unequal absorbent power of the membrane for these liquids depends on the dissimilar nature of the liquids or of the substances dissolved in them. An unequal proportion

(¹) I consider it of sufficient importance to state here that porous clay also takes up unequal volumes of brine and water. In special experiments made on this subject, cells of clay (moderately ignited porcelain biscuit) were laid for 24 hours in pure water, then carefully dried externally with bibulous paper, and the increase in weight, that is, the weight of the absorbed water, carefully determined.§ The clay was then carefully dried, laid for 24 hours in brine, and the weight of the absorbed brine determined in like manner. In a second series of experiments, the clay cells were steeped in water and brine, and placed in the receiver of the air-pump, under a pressure of 8 lines of mercury (⅔ of an inch) for 24 hours.

Under the ordinary pressure, and in air the cells absorbed—

		Weight.		Volume.	
		Water.	Brine.	Water.	Brine
100 parts of clay cell........	I.	15·4	14·6	15·4	12·2
	II.	11·8	11·6	11·8	9·7

In vacuo the cells of clay absorbed—

		Weight.		Volume.	
		Water.	Brine.	Water.	Brine.
100 parts of clay cell absorbed	I.	16·5	16·8	16·5	14·0
	II.	13·8	13·8	13·8	11·5

* Porous bodies in general exhibit similar phenomena.
† Bladder shrinks in contact with brine or alcohol.
‡ Change of volume in two liquids, separated by membrane, is accompanied by continual motion in the particles of the membrane; and depends on the unequal attraction of the membrane for the liquids.
§ Amount of liquids absorbed by porous baked clay.

of the same dissolved matters (unequal concentration,) acts in many cases, just as if the liquids contained dissimilar substances.

Although the experiments hitherto instituted, and the results obtained by FISCHER (who first observed these phenomena,) MANGUS, DUTROCHET, and others, admit of no comparison, since the apparatus used by them showed only relative change of volume, yet a knowledge of some of these results is, nevertheless, of importance.

When the two liquids are, diluted sulphuric acid (of sp. g. 1·093) and water, the acid, at 50° F., increases in volume; but if the acid have the specific gravity 1·054, the volume of the water increases,*

Diluted tartaric acid (11 parts of the crystalized acid and 89 of water) and water mix through a bladder without change of volume; with more than 11 per cent. of acid, the volume of the acid increases; with less that of the water.

Solutions of animal gelatine, gum, sugar, and albumen increase in volume when separated by a bladder from water; and the increase of volume in these different solutions, although of the same specific gravity, is very different indeed. When the specific gravity is 1·07, the increase in volume of the solution of gelatine amounts to 3, that of solution of gum to 5, of sugar 11, of albumen 12. When a solution of sugar (1 part of sugar to 16 of water) is separated by a bladder from water, it increases in volume; but if we add 1 part of oxalic acid to the sugar, the water, on the contrary, increases in volume. If the amount of sugar in the solution be doubled, the liquids mix without change of volume. A solution of sugar, separated by bladder from one of oxalic acid, rises, in the same time, 3 times higher than when separated from water. (DUTROCHET.)

From these experiments we obtain, as a universal result (which, however, requires confirmation,) that an animal membrane possesses a less power of absorption for solution of albumen than for all other organic substances :† and that a small amount of mineral or organic acids increases the power transudation of water as well as of the solutions of many organic substances.‡(1)

The rapidity of mixture of two liquids, separated by a membane, depends on the thicknes of the membrane, and stands in direct proportion to the velocity with which the mixture formed in the pores and on both surfaces of the bladder changes its place, and the original difference in the quality of the two liquids is renewed.§

‖ If we suppose a tube, formed of a membrane (an intestine, for example,) and filled with water, and if we assume that a current of saline solution flows round this tube, in consequenee of a mechanical force, the increase of volume of the brine (the passage into it of a certain amount of water) will be effected in a far shorter time than if the brine were not in motion.

The velocity of transference will diminish with the amount of difference in properties between the two liquids (the different amount or per centage of salt;)¶ it will be greatest at first, and diminish as the dilution of the brine increases, in proportion, that is to say, as water is transferred from the contents of the tube to the liquid without.

The greatest effect, therefore, must occur and be permanent, when the water transferred to the brine is continually again removed from it, that is, when the concentration of the brine is kept uniform.** To this end, if we suppose the membrane

(1)In order not to be misled in such experiments, we must avoid the employment of all those liquids which alter the membrane in its chemical properties. Such are, for example, acids of a certain concentration, nitrate of silver, salts of lead, chloride of gold, chloride of tin, chromic acid, bichromate of potash, taunic acid, &c. Even in water, the properties of membranes generally undergo a change after some days, they then propagate a far weaker hydrostatic pressure through their pores, and are no longer fit for such experiments.

* Examples of change of volume; in acids, and neutral organic substances, according to DUTROCHET

† Membranes have a feeble power of absorbing solution of albumen.

‡ Effect of adding acids.

§ Causes which influence rapidity of mixture.

‖ Motion of one of the liquids.

¶ Difference in properties of the two liquids.

** Effect of the continual removal of the transferred liquid analagous to suction.

to be difficultly permeable for one liquid, while the other is easily taken up into its pores, and if we reflect, that this second liquid, on entering into the pores of the bladder, in virtue of the attraction of their walls for it, acquires a certain velocity which permits it to pass beyond the extremitiss of the canal or the pores, so as to entirely fill the pores, and to come in direct contact with the liquid on the outside of the pores, it follows, that, when this second liquid moves past the poses with a certain velocity, the absorbed liquid must follow it during the mixture, and there must take place a rapid transference of the second liquid to the first, a true suction as if by a pump.

The animal body is an example of an apparatus of this kind in the most perfect form.* The blood vessels contain a liquid, for which their walls are, in the normal state, far less permeable than for all the other fluids of the body. The blood moves in them with a certain velocity, and is kept at all times in a nearly uniform state of concentration by a special apparatus, namely, the urinary organs.

The whole intestinal canal is surrounded with this system of blood vessels, and all the animal fluids, in so far as they are capable of being taken up by the parietes of the intestinal canal, and of the blood vessels situated around it, are rapidly mixed with the blood.† The volume of the blood increases, if no compensation is effected by means of the kidneys: and the intestine is emptied of the liquids contained in it. The intestinal glands, through which this transference is effected, and each of which represents a similar apparatus of suction, contain, within them, two systems of canals,—blood vessels and lacteals; the blood vessels are placed next to the external absorbent surface, the lacteals chiefly occupy the central part of the gland. The liquids circulating in these two systems have very unequal velocities, and as the blood moves much faster in the blood vessels, we perceive how it happens, that the fluids of the intestine are chiefly (in quantity and in velocity) taken up into the circulation.

The difference in the absorbent power of the parietes of the intestinal canal for liquids which contain unequal amounts of dissolved matters, is easily observed in the effects produced on the organism by water and saline solutions.‡

If we take while fasting, every ten minutes, a glass of ordinary spring water, the saline contents of which are much less than those of the blood, there occurs, after the second glass (each glass containing 4 ounces,) an evacuation of colored urine, the weight of which is very nearly equal to that of the first glass; and after taking, in this way, 20 such glasses of water, we have had 19 evacuations of urine, the last of which is colorless, and contains hardly more saline matter than the spring water.

If we make the same experiment with a water, containing as much saline matter as the blood ($\frac{3}{4}$ to 1 per cent. of sea salt,) there is no unusual discharge of urine, and it is difficult to drink more than three glasses of such water. A sense of repletion, pressure, and weight of the stomach point out, that water as strongly charged with saline matter as the blood requires a longer time for its absorption into the blood vessels.

Finally, if we drink a solution containing rather more salt than the blood, a more or less decided catharsis ensues.§

The action of solution of salt is of three kinds, according to the proportion of salt. Spring water is taken up into the blood vessels with great rapidity; while these vessels exhibit a very small power of absorption for water containing the same proportion of salt as the blood does; and a still more strongly saline solution passes out of the body—not through the kidneys, but through the intestinal canal.

Saline solutions and water, given in the form of enemata, exhibit similar phenomena in the rectum.‖ Pure water is very rapidly absorbed, and excreted

* This occurs in the animal body.
† Absorption of the liquids of the intestines into the blood.
‡ Effects produced by drinking water and saline solutions.
§ Solution containing more salt than the blood.
‖ Enemata of water and saline solutions.

through the urinary passages. If we add to the water colored or odorous matters, these appear, more or less changed in the urine. When a small quantity of ferrocyanide of potassium is added, its presence in the urine is very soon detected by chloride of iron, which forms with it Prussian blue. Of concentrated solutions far less is absorbed in the same time, than of diluted; in most cases they mix with solid matters collected in the rectum, and are expelled in the form of a watery dejection.

All salts do not act alike in this respect. In equal doses, the purgative action of Glauber salt and Epsom salt is far stronger than that of sea salt; and their power of being absorbed by animal membranes appears to be in the inverse ratio of this effect. It is hardly necessary, particularly to point out that an explanation of the action of purgatives in general cannot be included in the above-described action of saline solutions on the organism. The example which has been given is intended to illustrate a physical property common to a large number of salts, and apparently of the nature of the acid or base of the salt; for chloride of calcium, chloride of magnesium, bitartrate of potash, tartrate of potash and soda, phosphate of soda, and certain doses of tartar emetic, show the same action as sea salt, Glauber salt, and Epsom salt, although the bases and acids in these different salts are not the same.

Solutions of cane sugar, grape sugar, sugar of milk, and gum, exhibit, when separated from water by an animal membrane, phenomena similar to those exhibited by the above-named solutions of mineral salts, without causing in the living body a purgative action, when of equal concentration. The cause of this difference may be that the mineral salts, in their passage through the intestinal canal, and through the blood, are not essentially altered in their composition, while these organic substances, in contact with the parietes of the stomach, and under the influence of the gastric juice, suffer a very rapid change, by which the action which they have out of the body is arrested.

Since the chemical nature and the mechanical character of mebranes and skins exert the greatest influence on the distribution of the fluids in the animal body, the relations of each membrane presenting any peculiarity of structure, or of the different glands and systems of vessels, deserve to be investigated by careful experiment;* and it might very likely be found that in the secretion of the milk, the bile, the urine, the sweat, &c., the membranes and cell-walls play a far more important part than we are inclined to ascribe to them; that besides their physical properties, they possess certain chemical properties, by which they are enabled to produce decompositions and combinations, true analyses; and if this were ascertained, the influence of chemical agents, of remedies, and of poisons on those properties, would be at once explained.

The phonomena described in the preceding pages are observed, not in the gelatinous tissues alone, but also, apparently, in many other structures of the animal body, which cannot be reckoned as belonging to that class.†

If we tie moist paper over the open end of a cylindrical tube, and, after pouring in above the paper white of egg to the height of a few lines, place that end of the tube in boiling water, the albumen is coagulated, and when the paper is removed, we have a tube closed with an accurately fitting plug of coagulated albumen, which allows neither water nor brine to run through.‡ If the tube be now filled to one-half with brine, and immersed in pure water, as in Fig. 4, the brine is seen gradually to rise; and in three or four days it increases by from $\frac{1}{4}$ to $\frac{1}{2}$ of its volume, exactly as if the tube had been closed with a very thick membrane.

Influence of the cutaneous evaporation on the motion of the fluids of the animal body.

When a tube about 30 inches long, bent in the form of a knee, and widened at one end, is tied over at that end with a piece of moist ox-bladder, the bladder now

* Influence of membranes on secretions.
† These phenomena not confined to the gelatinous tissues.
‡ Coagulated albumen acts like a thick membrane.

thoroughly dried, and the tube filled with mercury and inverted, so that the open, narrow end stands in a cup of mercury, the mercury in the tube falls to about 27 inches (Hessian,) and remains, if the bladder have no flow, at that height, rising and falling as the mercury does in a barometer.

No air passes through the dry bladder into the Torricellian vacuum thus produced. When, by proper manipulation, we have allowed to pass out as much as can be removed of the air still contained in the tube, we have, in this arrangement, a barometer, containing no more air than would be found in one made with a similar tube hermetically sealed at the wide end, provided the mercury in the latter had not been boiled in the tube to expel the last traces of air. By the desiccation of the bladder, its pores, which allowed a passage to water, brine, oil, or even mercury, have obviously been closed by the adhesion of the successive layers of membrane, which perhaps cross each other, so that the bladder is not more permeable for the particles of air than a slice of horn of the same thickness.

Fig. 10.

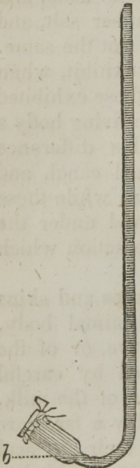
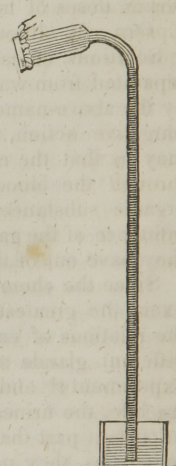


Fig. 11.



If we introduce water into the tube in the position, Fig. 10, to the line marked *b*, and, after filling the narrow part of the tube with mercury, invert it in a vessel of mercury, Fig. 11, we observe a number of minute bubbles of air passing through the moist bladder into the tube. The mercury falls to a certain point, which is higher or lower according to the thickness of the bladder; it stands at a lower level with a thin membrane than with a thick one. When a single layer of ox-bladder is used, it falls to 12 inches (above the level of the mercury in the vessel;) with a double layer it stands at from 22 to 24 inches.

If we take care to allow the water standing above the mercury to enter the wide part of the tube, so that the bladder is kept at all times covered with water, the mercury remains stationary at the same level. If, for example, it stood at 12 inches, it remains there, although the quantity of water is constantly diminishing by evaporation from the bladder; and it maintains its level, even after all the water has disappeared.

The height of the mercury in the narrow tube is an exact measure of the pressure acting on the surface of the bladder. The pressure in the inside of the tube is less than the existing pressure of the atmosphere outside by the height of that column of mercury.

This difference of level between the mercury in the vessel and that in the tube is the limit of the pressure, under which air passes into the water through the pores of the bladder; or under which the molecules of water in the pores are displaced by the molecules of air.

If we fill the tube entirely with water, and place the narrow end in mercury, while the wide end, closed with bladder, is exposed to the air, the mercury rises in the narrow limb, and at last reaches a point, identical with that to which it fell in the preceding experiment. For each specimen of bladder, according to its thickness, the level to which the mercury reaches is of course different.

When the diameter of the wide part of the tube, which is closed with bladder, is 12 millimetres, and that of the narrow tube 1 millimetre, the mercury rises, with ox-bladder, according to the temperature and the hygrometric condition of the air, to from 22 to 65 millimetres in one hour.

The cause of the rise of the mercury in this experiment hardly requires a special explanation.

The bladder is penetrated with water, covered on one side with water, and on the other in contact with a space (the air) not saturated with aqueous vapour The water contained in the pores of the side of the bladder turned towards the air evaporates; the space which it had occupied in the pores is filled with successive portions of water from within, in virtue of the attraction of the substance of the pores for water. The volume of the water in the tube diminishes, and thus a vacuum arises, in which the mercury is forced to rise by the atmospheric pressure. The space formerly occupied by the water which has evaporated is now filled with mercury.

When the mercury has reached a permanent level, the external pressure, which acts on the water in the pores of the bladder (and which tends to displace the particles of water) is obviously equal, before air enters, to the attraction which the substance of the bladder has for the particles of water, and these last to each other. Were the attraction less, air would enter, and the particles of water could not maintain their position.

The rise of the mercury, or its motion towards the surface of the bladder, that is, towards the point where evaporation is going on, is the result of a difference of atmospheric pressure, determined by the evaporation of the water, or of the liquid which penetrates through the bladder, and by the absorbent power of the bladder for that liquid.

One chief condition of the efficiency of a bladder, in regard to the rise of a coulmn of liquid, is, that it is kept constantly in contact with the liquid, for without this contact the absorbent power cannot manifest itself.

By the evaporation a continual efflux of water, in the form of vapour, towards the side on which the air lies, is produced; and by the capillary action of the bladder on the other side, water is absorbed and retained with a force which counterpoises 12 or more inches of mercury, according to the thickness of the bladder.

Now, since the rise of the mercury is an effect of the atmospheric pressure, it is plain, that the height to which the mercury rises, must depend to a certain degree on the state of the barometer.*

In a tube filled with water, and closed with bladder, the absorbent force of which is equal to the pressure of a column of 12 inches of mercury, the mercury rises by evaporation to the height of 12 inches, as long as a column of 12 inches of mercury can be sustained by the external atmospheric pressure. If this external pressure fall below that limit, the mercury in the evaporation tube falls to the same extent, and if there be water above the mercury, this water separates from the bladder.

This property of bladder, therefore, would appear unaltered at an elevation at which the barometer should stand at 12 inches; at a still greater elevation, on the contrary, the liquid would separate from the bladder.

The external pressure has no influence on the amount of the water evaporating in the pores of the bladder; that amount depends on the hygrometric state of the surrounding air, and on the temperature.† In a rarified air, (provided it can take up moisture,) evaporation goes on more rapidly than in a denser air; and hence it is clear, that at certain elevations, the effect of the bladder on the level of the liquid is more quickly produced than at the level of the sea. The amount of water which evaporates is directly proportional to the surrounding space, and to the temperature and corresponding tension of the liquid.

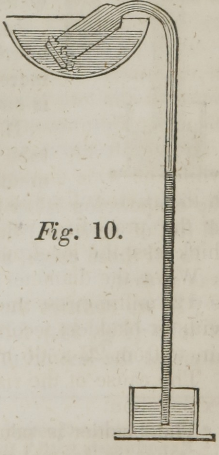


Fig. 10.

When the tube, Fig. 10, is filled with water to *b*, then entirely filled with mercury and inverted in mercury, the mercury, as we have seen, assumes a fixed level. If we now keep the upper or wide end of the tube, which is closed with bladder, immersed in a vessel of water, Fig. 12, we shall find, after a short time, that the mercury sinks in the narrow tube. If its level has been 12 inches above that of the mercury in the vessel, it sinks when the bladder is put into water, 3 or 4 inches for example, and remains stationary at 8 or 9 inches, without sinking further for the next 12 hours.

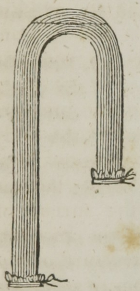
* Influence of the state of the barometer

† The pressure of the air does not affect the amount of evaporation.

The sinking of the mercury is caused by water being forced through the bladder into the tube, in virtue of the existence of an external pressure greater than the pressure on the inside of the tube.

To displace the aqueous particles in the pores of the bladder by other aqueous particles, requires obviously a much smaller pressure than is necessary to displace them by particles of air.* In the one case, where both surfaces of the bladder are in contact with the liquid, the attractive force (that of the bladder for the water and of the water for the bladder) is equal on both sides; but not so in the other case, where one side of the bladder is in contact with air. If the bladder had the same absorbent power for the particles of air as for those of water, the particles of air and water would pass through the bladder under the same pressure; the experiment shows, that the absorbent power and permeability of the bladder for air is far less than for water. Hence, it comes to pass, that when, with a given portion of bladder, in the apparatus Fig. 11, mercury is raised by evaporation to a heighth of 12 inches, less than 12 inches of mercury are required, in the apparatus, Fig. 1, to cause water to pass through the bladder.

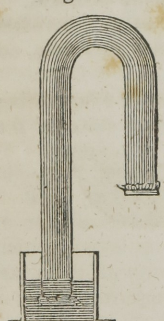
Fig. 13.



† When the tube, (Fig. 13,) is filled with water, closed with bladder at both ends, and exposed to evaporation, the bladders in a short time become concave, that is, they are pressed inwards. As the evaporation of the water through the moist surfaces of the bladder proceeds, there is formed in the upper part of the tube a vacuum, which is filled with aqueous vapor, and which continues to increase. The place of the water which evaporates is, as in the experiments previously described, gradually occupied by air, which enters the tube through the bladder.

It is evident, that when air enters the tube, (Fig. 13,) the pressure on the surface of the bladder is equal to the absorbent force of that bladder for the water. In the apparatus, Fig. 11, with the same bladder, the mercury might have been raised, in consequence of the evaporation, to a height of 4, 6, 12, or more inches, according to the thickness of the membrane.

Fig. 14.



When the longer limb of the bent tube, after it has been filled with water, and closed at both ends with bladder, is placed in a vessel containing brine, and exposed to evaporate in the air, as in Fig. 14, it is plain, that when the atmospheric pressure, increasing in consequence of the evaporation of the water on both the surfaces of the bladder, reaches the point at which the brine flows through the pores of the bladder, then the place of the water which evaporates is occupied by brine.

In fact, when the brine is colored blue, we observe, after a few hours, that a blue stratum forms within the tube, which constantly increases, till at last the vessel of brine is emptied, and the tube is entirely filled with brine.

If the longer limb be immersed in bile instead of brine, the tube fills with bile, and if we employ, for closing one end, a membrane rather thinner than we use for the other, from which the evaporation takes place, and then place the end with the thinner membrane in oil (oil of marrow,) the tube gradually fills with oil.

In all these cases, no air enters the tube, which continues full of liquid, as it was at first.

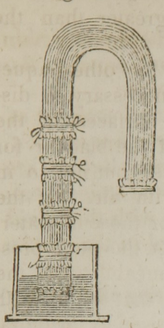
‡ If we connect the evaporation tube by collars of caoutchouc with short bits of tube (Fig. 15,) full of water, and tied with bladder at both ends; and if we immerse the last bit of tube in brine, urine, oil, &c., all these cells, and at last the

* Water passes through moist bladder more easily than air does.

† Experiments with a tube closed at both ends with bladder: with one end in brine, the tube being filled with water, with one end in bile, and in oil.

‡ Effect of a series of short tubes, closed at both ends with bladder.

Fig. 15.



evaporation tube itself, become gradually filled with brine, urine, oil, &c.

* The most general expression for these experiments and results is this;—that all liquids which are in connection with a membrane from the surface of which evaporation can take place, must acquire motion towards that membrane.

The amonnt of this motion is directly proportional to the rapidity of evaporation, and consequently to the temperature and hygrometric state of the atmosphere.

That the skin of animals, and the cutaneous transpiration, as well as the evaporation from the internal surface of the lungs, exert an important influence on the vital processes, and thereby on the state of health, has been admitted by physicians ever since medicine has existed; but no one has hitherto ascertained precisely in what way this happens.†

From what has gone before, it can hardly be doubted, that one of the most important functions of the skin consists in the share which it takes in the motion and distribution of the fluids of the body.‡

The surface of the body of a number of animals consists of a covering or skin permeable for liquids, from which, when, as in the case of the lung, it is in contact with the atmosphere, an evaporation of water, according to the hygrometric state and temperature of the air, constantly goes on.§

If we now keep in mind, that every part of the body has to sustain the pressure of the atmosphere, and that the gaseous fluids and liquids contained in the body oppose to this pressure a perfectly equal resistance, it is clear that, by the evaporation of the skin and lungs, and in consequence of the absorbent power of the skin for the liquid in contact with it, a difference in the pressure below the surface of the evaporating skin occurs. The external pressure increases, and in an equal degree the pressure from within towards the skin. If now the structure of the cutaneous surface does not permit a diminution of its volume, a compression (in consequence of the loss of liquid by evaporation,) it is obvious that an equalization of this difference in pressure can only take place from within outwards; first from within, and especially from those parts which are in closest contact with the atmosphere, and which offer the least resistance to the action of the external pressure.‖

Hence it follows, that the fluids of the body, in consequence of the cutaneous and pulmonary transpiration, acquire a motion towards the skin and lungs, which must be accelerated by the circulation of the blood.

By this evaporation, the laws of the mixture of dissimilar liquids, separated by a membrane, must be essentially modified.¶ The passage of the food dissolved in the digestive canal, and of the lymph into the blood vessels, the expulsion of the nutritive fluid out of the minuter blood vessels, the uniform distribution of these fluids in the body, the absorbent power of the membranes and skins, which, under the actual pressure are permeable for the liquids in contact with them, are under the influence of the difference in the atmospherical pressure, which is caused by the evaporation of the fluids of the skin and lungs.

The juices and fluids of the body distribute themselves, according to the thickness of the walls of the vessels, and their permeability for these fluids, uniformly through the whole body; and the influence which a residence in dry or in moist air, at great elevations or at the level of the sea, may exert on the health, in so far as the evaporation may thus be accelerated or retarded, requires no special explanation; while on the other hand the suppression of the cutaneous transpiration must

* Liquids move towards the membrane from which evaporation takes place.
† Influence of the skin and cutaneous transpiration on health.
‡ The cutaneous evaporation has an important share in causing the motion of the animal fluids.
§ Evaporation is constantly going on from the skin and lungs.
‖ This evaporation must produce unequal pressure, by which the fluids acquire a motion towards the skin and lungs.
¶ The change of pressure influences the mixture of the fluids.

be followed by a disturbance of this motion, in consequence of which the normal process is changed where this occurs.

The pressure, which, in consequence of the evaporation, urges the fluids within the body to move towards the skin, is, as may readily be understood, equal to the difference of pressure acting on the surface of the skin.*

From the experiment, Fig. 13, it is plain, that when one of the two surfaces of bladder at the ends of the tube Fig. 12, is exposed to atmospheric evaporation, while the other end is moistened with water, brine, or oil, these liquids are rapidly absorbed by the membrane, that is, are forced in by the external atmospheric pressure, and it is not less obvious, that the same thing takes place with the liquid with which one of the two evaporating surfaces has been moistened in the middle only; while the evaporation continues around the moistened spot.

If, therefore, we moisten with a liquid the surface of the evaporating skin at any point, the liquid is forced inwards by the external pressure.†

Let us suppose any part of the skin to be rubbed with fat, the transpiration ceases at that part.‡ If now the skin around the part is in its normal activity, if, therefore, in the surrounding parts liquid is constantly passing off by evaporation, the fat must be urged, by the unequal pressure thus arising, towards these parts, or it is absorbed, just as water, in the apparatus, Fig. 12, is absorbed, when in consequence of evaporation a difference between the internal and external pressure has arisen. If the whole skin were covered with fat, the absorption would be effected by the pulmonary evaporation.

The blistering of the skin, and the sun-burning, to which men are exposed at great elevations, arise from the extraordinary dryness of the air, the increased evaporation, and the pressure by which the fluids filling the vessels are forced towards the surface.

Several causes contribute jointly to the appearance of the sweat, to the efflux of fluid, from the pores of the skin. One of these obviously depends on the velocity, which the fluid set in motion by evaporation or by a mechanical cause, acquires from the accelerated motion of the blood. In consequence of this velocity, the fluid moves out beyond the limits of the absorbing membrane or skin.

The changes of the vital process, caused by the unequal distribution of fluid in the body in consequence of evaporation, are best seen in animals which live in water, in whom, therefore, the above explained cause of motion in the normal state does not act. When a fish is held immersed in water, so that the head is out of the water, while the rest of the body is covered, it dies in a few minutes.§ It dies exactly in the same way when head and gills are held in the water, and the body in air (Milne Edwards;) in both cases, without loss of weight. This fact shows that even if the weight of the animal be kept unaltered by the absorption of water through the body kept in that medium, yet the distribution of the fluids in the body does not take place in the proportion necessary for the preservation of their vital functions. The fish dies.

It is hardly necessary to remind the reader, that the experiments described in the foregoing pages, in so far as they permit us to draw conclusions as to the cause of the motion of the juices of the animal body, agree in all respects with the observations made on plants by Stephen Hales more than 120 years since.‖

The experiments of Hales on the mechanism of the motion of the sap, may stand as a pattern to all times of an excellent method. That they remain, to this moment, unsurpassed in the domain of vegetable physiology, may be, perhaps, explained by the fact that they date from the age of Newton. They ought to be familiar to every vegetable physiologist.

In the beginning of his work, Hales describes the experiments which he made

* The force urging the fluids towards the skin is equal to the difference of pressure acting on the skin.

† Liquids placed on the skin are absorbed by the evaporatiou of other parts.

‡ Effect of rubbing fat on a part of the skin or on the whole of it.

§ Fishes die in air, because the distribution of the fluids is prevented.

‖ Experiments of Hales on the motion of the sap in plants.

on the motion of the sap in plants in consequence of their evaporation in branches covered with foliage, in cut plants as well as in those still provided with roots.

He shows by the following experiment the influence of the mechanical pressure of a column of water, with and without the help of evaporation.

To a branch of an apple tree bearing its twigs and leaves, HALES fastened, air-tight, a tube seven feet long. He kept the branch with its twigs and leaves immersed in a large vessel of water, and filled the tube with water. By the pressure of the column of water, water was forced into the branch, and in two days the water in the tube had sunk $14\frac{1}{4}$ inches.

On the third day, he took the branch out of the water, and exposed it to free evaporation in the air. The water in the tube fell, in twelve hours, 27 inches.

To compare the force with which water is driven through the vessels of the wood, by pressure alone, with that produced by pressure and evaporation, he joined an apple branch, 6 feet long, with leaves, and exposed to the air, with a tube 9 feet long, which was filled with water.

From the pressure caused by the column of water, and by the evaporation going on at the surface of the twigs and leaves, the water fell (XIth experiment,) *in one hour*, 36 inches. He now cut off the branch 13 inches below the tube, and placed the portion cut off (with the twigs and leaves) vertically in a vessel of water. This last absorbed, in 30 hours, 18 ounces of water, while the portion of wood remaining in connection with the tube, which was 13 inches long, only allowed 6 ounces of water to pass, and that under the pressure of a column of 7 feet of water.

HALES shows in three other experiments, that the capillary vessels of a plant, alone, and in connection with the uninjured roots, are easily filled with water by capillary attraction, without, however, possessing the power of causing the sap to flow out and to rise in a tube attached.* The motion of the sap, concludes HALES, belongs to the evaporating surface alone; he proves that it goes on in an unequal degree from the stem, the twigs, the flowers, and fruit, and that the effect of the evaporation stands in a fixed ratio to the temperature and hygrometic state of the air. If the air were moist, but little were absorbed; the absorption was hardly perceptible on rainy days.

He opens the second chapter of his Statistics with the following introduction:—

"Having in the first chapter seen many proofs of the great quantities of liquor imbibed and perspired by vegetables, I propose in this, to inquire by what force they do imbibe moisture. Though vegetables (which are inanimate) have not an engine, which by its alternate dilations and contractions, does in animals, forcibly drive the blood through the arteries and veins; yet has nature wonderfully contrived other means, most powerfully to raise and keep in motion the sap.

In his experiment XXI., he exposed one of the chief roots of a pear tree in full growth at a depth of $2\frac{1}{2}$ feet, cut off the point of it, and connected the part of the root left in connection with the stem with a tube which he filled with water and closed with mercury.

In consequence of the evaporation from the surface of the tree, the root absorbed the water in the tube with such a force, that in six minutes the mercury rose to 8 inches in the tube. This corresponds to a column of water 9 feet high.

This force is nearly equal to that with which the blood moves in the great femoral artery of the horse. HALES, in his experiment XXXIV., found the force of the blood in various animals; "By tying those several animals down alive upon their backs, and then laying open the great left crural artery, where it first enters the thigh, I fixed to it (by means of two brass pipes which run one into the other) a glass tube of above 10 feet long, and $\frac{1}{8}$th of an inch in diameter in bore. In which tube the blood of one horse rose 8 feet 3 inches, and the blood of another horse 8 feet 9 inches. The blood of a little dog $6\frac{1}{2}$ high."

HALES showed by special experiments, that the absorbent force which he pointed out in the root is found also in the stem, in each separate twig, each leaf, and every part of the surface; and that the motion of the sap continues from the root towards

* The motion of the sap is caused by the evaporating surface.

the twigs and leaves, even when the stem has been entirely stripped of bark, inner and outer. This force acts not only from the roots in the direction of the summit but also from the summit in the direction of the root.

From his experiment he deduces the presence of a powerful attractive force residing in every part of the plant.

We now know, that this attractive force, as such, did not cause the rise of the mercury or water in his tubes, and it appears clearly from his experiments, that the absorbent power of plants, of each leaf, of each fibre of the root, is sustained by a powerful external force which is nothing else than the pressure of the atmosphere.*

By the evaporation of water at the surface of plants, a vacuum arises within them, in consequence of which water and matters soluble in water are driven inwards and raised from without with facility, and this external pressure, along with capillary attraction, is the chief cause of the motion and distribution of the juices.†

With respect to the absorbent power of the plant for gases, under a certain external pressure, his experiments offer the most beautiful evidence.‡ HALES says, in his experiment XXII., "This height of the mercury did in some measure show the force with which the sap was imbibed, though not near the whole force; for while the water was imbibing, the transverse cut of the branch was covered with innumerable little hemispheres of air, and many air-bubbles issued out of the sap-vessels, which air did, in part, fill the tube *e r*, as the water was drawn out of it; so that the height of the mercury could only be proportionable to the excess of the quantity of the water drawn off, above the quantity of air which issued out of the wood. And if the quantity of air which issued from the wood into the tube, had been equal to the quantity of water imbibed, then the mercury would not rise at all; because there would be no room for it in the tube. But if 9 parts of 12 in the water be imbibed by the branch, and in the mean time, but three such parts of air issue into the tube, then the mercury must needs rise near 6 inches, and so proportionably in different cases."

When, in his experiments, the root, the stem, or a twig had been injured at any part, by the cutting off of buds, root-fibres, or small twigs, the absorbent power of the remainder was diminished in a very obvious degree (because, from these places, by the entrance of air the difference of air was more easily equalized;)§ the absorbent power was greatest on freshly-cut surfaces, on which, however, it gradually decreased, till, after several days, it was not greater in these places than in the uninjured surface of the plant.

The evaporation, further, argues HALES, is the powerful cause which provides food for the plant and its vicinity. Disease and death of the plant follow, when the proportion between evaporation and supply is interrupted or destroyed in any way.||

When, in hot summers, the earth cannot supply, through the roots, the moisture which during the day has evaporated through the leaves and surface of the tree, when the tree, or a twig of it, dries up, the motion of the sap is arrested at these points. When once dried, capillary action alone cannot restore the original activity; the evaporation is the chief condition of the life of plants; by its means a permanent motion, a continually repeated change in the quality of the juice (sap) is effected.

"By comparing," says HALES, "the surface of the roots of plants, with the surface of the same plant above ground, we see the necessity of cutting off many branches from a transplanted tree: for if 256 square inches of root in surface was necessary to maintain this cabbage in a healthy natural state; suppose upon digging it up, in order to transplant, half the roots be cut off (which is the case of most young transplanted trees,) then it is plain that but half the usual nourishment can be carried up, through the roots, on that account; and a very much less pro-

* The pressure rf the atmosphere is the active force.
† A partial vacuum is caused within plants by evaporation.
‡ The surface of plants absorbs gases.
§ The absorbent power diminished by injury to the plant.
|| Evaporation provides food for the plant.

portion, on account of the small hemisphere of earth the new-planted, shortened roots occupy; and on account of the loose position of the new-turned earth, which touches the roots at first but in few points."

HALES proves the influence of suppressed evaporation by the following observations on hop-vines.

"Now there being 1,000 hills in an acre of hop-ground, and each hill having three poles, and each pole three vines, the number of vines will be 9,000; each of which imbibing four ounces, the sum of all the ounces, imbibed in an acre in a twelve hours' day, will be 36,000 ounces = 15,750,000 grains = 62,007 cubic inches, or 220 gallons; which divided by 6,272,640, the number of square inches in an acre, it will be found, that the quantity of liquor perspired by all the hop-vines, will be equal to an area of liquor, as broad as an acre, and $\frac{1}{101}$ part of an inch deep, besides what evaporated from the earth. And this quantity of moisture in a kindly state of the air is daily carried off in a sufficient quantity to keep the hops in a healthy state; but in a rainy moist state of air, without a due mixture of dry weather, too much moisture hovers about the hops, so as to hinder in a good measure the kindly perspiration of the leaves, whereby the stagnating sap corrupts, and breeds mouldy fen, which often spoils vast quantities of flourishing hop-grounds."

"This was the case in the year 1723, when ten or fourteen days' almost continual rains fell, about the latter half of July, after four months' dry weather; upon which the most flourishing and promising hops were all infected with mould or fen, in their leaves and fruit, whilst the then poor and unpromising hops escaped, and produced plenty; because they, being small, did not perspire so great a quantity as the others; nor did they confine the perspired vapor, so much as the large thriving vines did, in their shady thickets. This rain on the then warm earth made the grass shoot out as fast as if it were in a hot-bed; and the apples grew so precipitately, that they were of a very fleshy constitution, so as to rot more remarkably than had ever been remembered."*

"The planters observe, that when a mould or fen has once seized any part of the ground, it soon runs over the whole; and that the grass, and other herbs under the hops, are infected with it."

"Probably because the small seeds of this quick-growing mould, which soon come to maturity, are blown over the whole ground. Which spreading of the seed may be the reason why some grounds are infected with fen for several years successively."

"I have in July (the season for fire-blasts, as the planters call them) seen," says HALES, "the vines in the middle of a hop-ground all scorched up, almost from one end of a large ground to the other, when a hot gleam of sunshine has come immediately after a shower of rain; at which time the vapors are often seen with the naked eye, but especially with reflecting telescopes, to ascend so plentifully, as to make a clear and distinct object become immediately very dim and tremulous. Nor was there any dry gravelly vein in the ground, along the course of this scorch. It was, therefore, probably owing to the much greater quantity of scorching vapors in the middle than outsides of the ground, and that being a denser medium, it was much hotter than a more rare medium."

"This is an effect which the gardeners about London have too often found to their cost, when they have incautiously put bell-glasses over their cauliflowers early in a frosty morning, before the dew was evaporated off them; which dew being raised by the sun's warmth, and confined within the glass, did there form a dense, transparent, scalding vapor, which burnt and killed the plants."

When these observations are translated into our present language, we perceive with what acuteness and accuracy HALES recognized the influence of evaporation on the life of plants.

According to him the development and growth of the plant depends on the supply of nourishment and moisture from the soil, which is determined by a certain

* Observations of Hales on the blight in hops and other plants.

temperature and dryness of the atmosphere. The absorbent power of plants—the motion of their sap, depends on evaporation; the amount of food necessary for their nutrition, which is absorbed, is proportional to the amount of moisture given out (evaporated) in a given time. When the plant has taken up a maximum of moisture, and the evaporation is suppressed by a low temperature or by continued wet weather, the supply of food, the nutrition of the plant, ceases; the juices stagnate, and are altered; they now pass into a state in which they become a fertile soil for microscopic plants. When rain falls after hot weather, and is followed by great heat without wind, so that every part of the plant is surrounded by an atmosphere saturated with moisture, the cooling due to further evaporation ceases, and the plants are destroyed by fire-blast or schorching (*Sonnenbrand*, German, literally, sun-burn or sun-blight.)

After the experience and observations of so long a period in reference to the influence of evaporation on the condition of plants, I hardly think that any unprejudiced observer can entertain the smallest doubt concerning the cause of the great mischief which has befallen agriculture during the last few years.* If HALES, that unequalled observer and inquirer, had known the potato disease, I hardly believe that he would have ascribed it to an internal cause belonging to the plant, any more than he thought of ascribing the blight of the hop plants, formerly mentioned, to a special hop disease, or the rotting of the apples to an apple disease. Even PARMENTIER, to whom France is indebted for the introduction of the potato, knew this disease, and has very accurately described it.† The term "potato-rot" has been known to the oldest peasants and agriculturists since their youth; it has, doubtless, only acquired of late years the frightful significance, which seems to threaten the well being of nations, since the causes, which formerly brought it locally into existence, have spread over whole districts and countries. The writings of HALES bring to our century from a preceding one the consoling certainty (and this is especially important,) that the cause of this decay is not to be looked for in a degeneration of the plant, but depends on the combination of certain conditions accidentally coincident; and that these, when they are well ascertained and kept in view, enable the agriculturist, if not to annihilate, at least to diminish, their hurtful influence.‡

The potato plant obviously belongs to the same class of plants as the hop plant, namely, to that class which is most seriously injured by the stagnation of their juices in consequence of suppressed transpiration.§ According to KNIGHT, the tubers are not formed by swelling of the proper roots, but by the development of a kind of underground stalks or runners. He found that when the tubers under ground were suppressed, tubers were formed on the stalks above ground; and it is conceivable that every external cause which exerts a hurtful influence on the healthy condition of the leaves and stalks, must act in like manner on the tubers. In the districts which were most severely visited by the so-called potato disease in 1846, damp, cold, rainy weather followed a series of very hot days; and in 1847, cold and rain came on, after continued drought, in the beginning of September, exactly at the period of the most luxuriant growth of the potatoes.‖

In most places, no trace of disease was observed in the early potatoes before the middle of August; and even after that period low-lying, cold and wet fields, were chiefly attacked by it. In many plants, in the same field, in which the seed potatoes had been destroyed by putrefaction and decay, the tubers appeared quite healthy, while in others it was easy to see that these tubers alone, which lay next to the old potatoes, were infected and attacked by the disease, and that on the side next to the old tubers.¶

In 1846 all the potato plants in my garden died completely off towards the end of August, before a single tuber had been formed; and in 1847, in the same field,

* The potato blight has probably a similar origin.
† The potato blight has been long known.
‡ It is not due to a degeneration of the plant, but to a combination of external causes.
§ The potato plant is one of those which suffers most from suppressed evaporation.
‖ Character of the weather in 1846 and 1847, when the potato blight prevailed.
¶ In most places the early potatoes escaped till after the middle of August.

the tubers of all those plants which stood under trees, and in protected spots, were quite rotten, while no trace of disease appeared in spots which were more elevated and more fully exposed to the current of air. The cause of the disease is the same which, in spring and autumn, excites influenza; that is, the disease is the effect of the temperature and hygrometric state of the atmosphere, by which, in consequence of the disturbance of the normal transpiration, a check is suddenly, or for a considerable time, given to the motion of the fluids, which is one chief condition of life, and which thus becomes insufficient for the purposes of health, or even hurtful to the individual.*

The whole existence of a plant, the resistance which it opposes to the action of the atmospheric oxygen, is most closely connected with the continued support of its vital functions. The mere alternation of day and night makes, in this respect, a great difference. The sinking of the external temperature by a few degrees, causes the leaves to fall in autumn; and a cold night is followed by the death of many annual plants.

If we reflect that a plant, in order to protect itself from external causes of disturbance, or to seek the food which it requires, cannot change its place; that its normal vital functions depend on the simultaneous and combined action of water, of the soil, of the external temperature, and of the hygrometric state of the atmosphere; that is, on four external circumstances; it is easy to comprehend the disturbance of functions which must occur in the organism in consequence of any change in the mutual relations of so many combined agencies.† The state of a plant is a sure indication of equilibrium or misproportion in the external conditions of its life; and the dexterity of the accomplished gardener consists exactly in this, that he knows and can establish the just proportion of these conditions for each species of vegetable. Only one of these numerous conditions is in the power of the agriculturist, and that is, the production of the quality of the soil appropriate for the crop, including the necessary modification of its composition, by the mechanical working of the soil; by the irrigation or draining of the fields; and lastly, by the employment of manure. When one of the constituents of the soil, which, under the given circumstances, is necessary for the support of the vital functions, is absent, the external injurious influence is strengthened by this deficiency. Had this constituent been present, the plant would have been enabled to oppose to the external hurtful influences a continued resistance. One day may be decisive as to the life or death of a plant.‡ An accurate knowledge of the influence exerted by the various constituents of the soil on the diseased condition, must enable the agriculturist to protect and preserve many of his fields for a long time from this destruction; but it is obvious that a universal remedy against this evil does not exist.

When the vessels of the plant are filled to overflowing with water, and the motion of the sap is suppressed, the nutrition, in most plants, is arrested, and death takes place. Every one knows the effect of a sudden or of a gradual overfilling of certain parts or organs, when the corresponding evaporation is suppressed. By the endosmotic pressure of the water flowing towards those cells, which contain sugar, mucilage, gum, albumen, and soluble matters in general, the juicy fruits and seeds approaching maturity burst, and the juice of grapes, cherries, plums, &c., passes, on contact with the air, into a state of progressive change. The fungi which have been observed on the potato plants and the putrefaction of the tubers, are not the signs of a disease, but the consequences of the death of the plant.§

Among the most important of the experiments made by Hales we must reckon undoubtedly those on the rise of the spring sap in perennial plants. His observations have been entirely confirmed by all those who since his time have studied the subject; but, in my opinion, without our having approached one step nearer to the cause of the phenomena.

* The cause of potato blight is the same as that of influenza, and depends on the temperature and hygrometric state of the air.

† The life of plants is dependent chiefly on four external causes: only one of which, namely, the quality of the soil, in the power of the agriculturist.

‡ Effects of the presence or absence of a single constituent of the soil.

§ The plant dies, and fungi and putrefaction follow.

The most recent experiments on this subject by E. Brücke, leave no doubt in regard to the actual state of our knowledge.

According to Dutrochet, it is the extremities of the radical fibres, called by De Candolle, spongioles, which effect the rise of the spring sap; and he believes (L'agent immèdiat du mouvement vital, Paris,1826,) that the force with which the sap is driven upwards, acts from the root. Dutrochet cut off a peice of a vine stem, two metres long; and he saw that the sap flowed steadily from the shortened stem in connection with the root. When he had again cut it off close to the ground, he observed the portion in the ground continued to pour forth sap from the whole cut surface. He pursued the experiment, going deeper every time, and he always found that the sap flowed from the part left in the ground, till at last he came to the extreme points of the fibres, in which he then located the origin of the moving force.

The peculiar activity of the spongioles must, according to Dutrochet, be ascribed to all the causes, taken together, which determine the phenomena of endosmosis.

Now that we are better acquainted with the phenomena of what is called endosmosis, we may oppose to this view some well founded doubts. All observers agree, that the increase in volume of a liquid, separated from another liquid by a porous diaphragm, is determined by a difference in the qualities of the two liquids. If their composition and properties be the same, there is no cause sufficent to produce mixture and change of volume, since in this case, the attraction of both for the diaphragm, and for each other, is perfectly equal.

In the course of his admirable researches, Brucke determined the specific gravity of the spring sap which had flowed from the vine.* He found it, in one plant, = 1·0008, and in another, = 1·0009.(1)

These numbers prove irresistably, that in the specific gravity of the sap of the vine is in no way different from that of ordinary spring water, or of the water which has filtered through garden mould. In most cases, spring water contains even more dissolved matter.

The spring sap of the vine, which had the sp. g. 1·0008, raised a column of mercury to the height of 174 lines (14·5 inches,) and therefore exerted a pressure equal to that of a column of water 195 inches high. It is quite impossible to account for this pressure by the difference in the amount of dissolved matter in the water absorbed by the roots, and the sap flowing from the cut surface. In the experiment No. IX., of Brucke, made with a vine, the sap of which had the sp. g. 1·0009 the mercury was raised at 7 a. m., to the height of 209 lines, (nearly 17·5 inches.

No one can doubt that what is called endosmosis has some share in the rise of the sap of the maple and birch trees, which is proportionally rich in sugar, and differs materially in composition from spring water, as well as on the flow or exudation of gummy or saccharine juices; but the pressure exerted in these cases, cannot be compared to that exerted by the sap of the vine, where the causes included under the word endosmosis cannot act.

It is evident, that the cause of the pressure of the spring sap must be transient, called into action by external causes, and limited to a short period.† The experiment of Dutrochet, from which he concludes that the cause of the rise of the sap resides in the extreme points of the roots, may be thus interpreted :—" The cause of the efflux and pressure of the sap exists in all parts of the uninjured plant, down to the extreme spongioles of the root."

The present season does not admit of experiments on this point; but as spring approaches, it may be proper here to develope more clearly the grounds of the opinion, that the cause of the efflux of the sap of the vine is a transient one. Perhaps some one may thus be induced to decide experimentally all the questions of this remarkable phenomenon.

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(1) Poggendorf's Annalen der Physik, lxiii. 177.

* Observations of Brucke on the specific gravity of the sap of vines.

† The cause of the rise of the sap is transient; and depends on external influences

Hales, in his experiment XXXIV., cut off a vine stem 7 feet above the ground, and attached to the trunk tubes of 7 feet long, joined together. Below the cut there were no branches. This was done on the 30th of March, at 3 P.M.

As the stem poured out no sap on that day, he poured water into the attached tube to the height of two feet.

This water was absorbed by the stem, so that about 8 P.M., the water had fallen to 3 inches in the tube.

The next day, ½ past 6 A. M., the sap stood 3 inches higher than at 8 the evening before. From this time the sap continued to rise, till it reached a height of 21 feet. It would perhaps, says Hales, have risen higher, had the joinings of the tubes been more water-tight.

Whatever opinion we may entertain as to the cause of the efflux and pressure of the sap, it is impossible to suppose that the mechanical or any other structure or quality of the radical fibres, the spongioles, or the inner parts of the vine stem generally, can have changed so much between the evening of the 30th and the morning of the 31st, as to give rise to two completely opposite influences.

On the evening of the 30th the water poured into the tube was absorbed; on the 31st it was expelled with a continually increasing force.

In his experiment XXXVII., Hales fixed, on three branches of a horizontally trained espalier vine, siphon tubes, filled to a certain point with mercury.

The three branches received their sap from the common stem, that stem from the root. The first branch was 7 feet from the second, the second 22 feet 9 inches from the third. The first and third branches were two years old, the middle one was older.

From the 4th to the 20th of April, the mercury stood, in consequence of the pressure of the sap, higher in the open limb of the tubes than in the other which was attached to the branch.

The greatest height attained by the mercury was from 21 to 26 inches.

On the 21st of April, when the flowering was nearly over, the sap in the middle branch went backwards; it was absorbed, and so considerably, that the mercury stood 4 inches lower in the open limb than in the other. After a rainy night on the 24th of April, the sap again rose in the open tube 4 inches.

In the first (lowest) branch, the sap went back on the 29th of April, 9 days after the middle one; the third (highest) branch only began to absorb the sap on the 3d of May, thirteen days after the middle one.

We see from this experiment, as Hales observes, "That the cause which produces the flow of the sap does not proceed from the root alone, but that it belongs to a force inherent in the stem and branches. For the middle branch followed more rapidly the changes of temperature, of dryness and of moisture, than the two others, and absorbed the sap nine days before one, and thirteen days before the other, both of which, during this time, poured out sap instead of absorbing it. (The cause of the efflux and pressure had, in the older branch, disappeared, and given place to an opposite influence, while it still continued active in the two younger branches.)

"The middle branch was 3 feet 8 inches higher than that next the stem. The height of the mercury in the three tubes was, respectively, 14½, 12½, and 13 inches. The maximum was 21, 26, and 26 inches. These numbers prove that the greater length of the middle branch had no perceptible influence on the height of the mercury, as compared with that in the other tube."

In his experiment XXXVIII., Hales observes,—"Moisture and warmth made the sap most vigorous. If the beginning or middle of the bleeding season, being very kindly, had made the motion of the sap vigorous, that vigor would immediately be greatly abated by cold easterly winds.*

"If in the morning while the sap is in a rising state, there was a cold wind with a mixture of sunshine and cloud; when the sun was clouded the sap would immediately visibly subside, at the rate of an inch in a minute for several inches, if the sun continued so long clouded; but as soon as the sunbeams broke out

* Effect of cold and of shade on the rise of the sap.

again, the sap would immediately return to its then rising state, just as any liquor in a thermometer rises and falls with the alternacies of heat and cold ; whence it is probable, that the plentiful rise of the sap in the vine in the bleeding season, is effected in the same manner."

If we consider, that the sap in spring, even with a clouded sky, does not cease to rise and flow, for this even goes on during the night, we cannot explain the fall of the sap from the moment that the sun was covered by a cloud by a mere change of temperature in the juice, because the time was too short for the cooling and contraction by cooling (one inch in a minute.)* Heat determined the more rapid rise, and cold the fall, but they acted on a cause which lay higher than the root, and which was more sensitive to heat than the liquid itself.

Hales says, in his experiment XXXVIII.—"In very hot weather many air bubbles would rise, so as to make a froth an inch deep, on the top of the sap in the tube.†

"I fixed a small air pump to the top of a long tube, which had twelve feet height of sap in it; when I pumped, great plenty of bubbles arose, though the sap did not rise, but fell a little, after I had done pumping."

In his experiments on the amount of air absorbed by plants, chapter V., he observes, "in the experiments on vines, the very great quantity of air which was continually ascending from the vines, through the sap in the tubes; which manifestly shows what plenty of it is taken in by vegetables, and is perspired off with the sap through the leaves."

When we take these facts into consideration, the opinion appears not untenable, that the incomprehensible force, which causes the sap of the vine to flow in spring, may be simply referred to a disengagement of gas which takes place in the capillary vessels (filled with liquid, and keeping themselves constantly full,) in consequence of a kind of germination; and it is possible that the height of the column of mercury, or of water, is only a measure of the elasticity of the disengaged gas.‡

Let us suppose a strong glass bottle, in the mouth of which a long tube, open at both ends, and reaching to the bottom, is cemented, to be filled with a liquid in which, from any cause, a gas is disengaged (solution of sugar mixed with yeast, for example,) it is evident that the liquid must rise in the tube from the separation of the gas. When it has risen to 32 feet, the gas will occupy only the half, and at 64 feet, one third of its volume under the usual atmospheric pressure. In this case, the height of the liquid in the tube is no measure of a special power residing in the walls of the vessel; it only shows the tension of the gas.

If the walls of the vessel were permeable to the gas under a certain pressure, no further rise, beyond that point, could occur.

If, in the apparatus, Fig. 4, we push the tube *a* through the cork down to the little lead drop; if we then fill the tube *c* with water to which some yeast has been added, and *a* with solution of sugar, and expose the whole to a temperature of from 68° to 75°, the liquid rises in *b*, from the gas disengaged in *c*, very rapidly, so as to overflow. If *c* be filled with solution of sugar, and *a* with yeast, the same rise occurs, and lasts till the disengaged gas puts an end to the contact between the membrane and the liquid.

It is hardly necessary to point out, that the idea above expressed as to the cause of the flow and pressure of the spring sap, is nothing more than an indication of the direction in which experiments must be made. When we know with accuracy the volume of the liquid which flows out of a vine at the time of flowering, and the quantity of gas which is developed at the same time, we shall, I trust, find ourselves a step nearer to the explanation of this phenomenon. According to the experiments of Geiger and Proust, the sap of the vine is rich in carbonic acid; and it is possible that the gas which is disengaged, may be no other than carbonic acid gas.

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* How is this effect to be accounted for?
† Gas is given off with the sap.
‡ The rise of the sap may, therefore, be caused by th evolution of gas.

APPENDIX.

ON THE NATURE AND PREVENTION OF THE POTATO DISEASE.

AFTER the preceding pages were in print, I received from Baron Liebig a copy of the Journal of the Agricultural Association of the Grand Duchy of Hesse, (Darmstadt,) No. 7, dated 15th February, 1848, containing the account of a method proposed by Dr. Klotzsch (Keeper of the Royal Herbarium, Berlin, and a distinguished Botanist and Vegetable Physiologist,) for preventing the ravages of the potato disease. The proposal of Dr. Klotzsch, and his views as to the nature of the disease, are such as materially to strengthen the opinions expressed on this subject by Baron Liebig, (see pp. 87, seq.) As a knowledge of the method suggested by Dr. Klotzsch is likely to be interesting to many of the readers of this work, I have thought it right to give it in an Appendix.

WILLIAM GREGORY.

METHOD PROPOSED BY DR. KLOTZSCH, FOR THE PROTECTION OF THE POTATO PLANT AGAINST DISEASES.

The potato, which is an annual plant, represents, in the tubers developed from the stem, the perennial part of a plant. For while the duration of its development is analogous to that of annuals, its functions coincide exactly with those of dicotyledonous shrubs and trees.

" The potato plant differs from all those plants which are cultivated for economical purposes in Europe, and can only be compared to those orchideous plants which yield salep, and which are not yet cultivated among us.

" The tubers, both of the potato and of the salep plants, are nutritious, and agree in this, that in the cells of the tubers, grains of starch, with more or less azotized mucilage, are collected, while the cell walls possess the remarkable property of swelling up into a jelly, and thus becoming easily digestible, when boiled with water.

" But while the tuber of salep contains only one bud, or germ, the potato usually develops several, often many, germs.

" The potato plant, like all annuals, exerts its chief efforts in developing flowers and fruit. Like all annuals, too, it has the power of shortening this period of development, when the power of the roots is limited; as also of lengthening it when the extent and power of the roots are increased.

We observe in nature that plants with feebly developed roots often have a weak, sickly aspect, but yet come to maturity in flower and fruit sooner than stronger individuals, well furnished with roots.

"In perennial plants we observe a second effort, which is directed towards preparing and storing up nutritious matter, for the consumption of the plant. The preparation of this nutriment is effected by the physiological action of the leaves, under the influence of the roots. The stronger and larger the former are, the more is this preparation of food delayed.

"The nutritious matters are stored in the colored stratum of the bark in shrubs and trees, and in the tubers in the potato and salep plants. Not only, however, the nutrient matters, but also the cells, owe their origin to the physiological action of the leaves.

"On considering these things, it follows, that the potato plant requires more care than is usually devoted to it. Hitherto the whole cultivation consisted in clearing off weeds, and hoeing up the earth round the stems. Both of these measures are, indeed, necessary, but they are not alone sufficient; for the plant is cultivated, not on account of its fruit, but for the sake of its tubers, and our treatment should be modified accordingly.

"The chief points to be attended to, with a view to the attainment of this object, namely, the increase of tubers, are—

1. To increase the power in the roots, and
2. To check the transformation which occurs in the leaf.

"We obtain both ends simultaneously, if, in the 5th, 6th, and 7th week after setting the tubers, and in the 4th and 5th week after planting out germs furnished with roots, or at a time when the plants reach the height of 6 to 9 inches above the soil, we pinch off the extreme points of the branches or twigs to the extent of half an inch downwards,* and repeat this on every branch or twig, in the 10th and 11th week, no matter at what time of day.

"The consequences of this check to the development of the stem and branches, is a stimulous to the nutrient matters in the plant in the direction of the increase, both of roots and of the multiplication of the branches of the stem above ground, which not only favors the power of the root, but also strengthens the leaves and stalks to such a degree, that the matters prepared by the physiological action of these parts are increased and applied to the formation of tubers, while at the same time the direct action of the sun's rays on the soil is prevented by the thick foliage, and thus the drying up of the soil and its injurious consequences are avoided.

The checking of the transformation in the leaf is equivalent to the interruption of the natural change of the leaves into calyces, corollæ, stamens, and pistils, which is effected at the expense of the nutrient matters collected in the plant; and these, when this modification of the leaves is arrested, are turned to account in the formation of tubers.

"Led by these views, I made, in 1846, experiments on single potato plants, carefully marked by pinching off the ends of the branches. They were so readily distinguished in their subseqnent growth from the plants beside them, by more numerous branches, larger and darker foliage, that in truth no marking was necessary.

"The produce from these plants of tubers was abundant, and the tubers were perfectly healthy; while the plants next them which had not been so treated, gave uniformly less produce, at the same time the tubers were rough on the surface, and in many instances attacked with the prevailing disease. This experiment was incomplete, and did not give a positive result, but it was yet encouraging for me.

"In the middle of April, 1847, an experiment was made on a low-lying field with the round white potatoes, generally cultivated here, a variety which had not suffered much from the disease which first appeared here 1845. The potatoes were planted in the usual way by an experienced farm servant.

"After weeding them in the end of May, I renewed my experiment by pinching off the points of the branches of every second row, and repeated this in the end of June. The result surpassed all expectations. The stocks of the plants not treated

* Any one would be bitterly disappointed, who on the principle, that "there cannot be too much of a good thing," should take off more than is here recommended, in order to use it as fodder.

on my plan, were long, straggling, and sparingly furnished with leaves, the leaves themselves, small and pale green.

"In the next field, potatoes of the same variety were planted on the same day and left to nature. They appeared in the first six weeks healthy, even strong, but gradually acquired a poor aspect as the time of flowering and fruit approached, and finally, exhibited precisely the same appearance as the rows not treated by pinching off the extremities in the field in which my experiments were made.

"The harvest began in the surrounding fields in the middle of August, and was very middling. The tubers were throughout smaller than usual, very scabby, and within these fields, to a small extent, attacked by the wet rot.

"In the end of August, the difference between the rows treated by me and those not treated, became so striking that it astonished all the work people in the neighborhood, who were never tired of inquiring the cause. The stocks of the rows left to themselves were all now partly dried, partly dead. On the contrary, the rows treated as above were luxuriant and in full vigour, the plants bushy, the foliage thick, the leaves large and green, so that most people suppposed they had been later planted.

"But the difference in the tubers was also very decided. The tubers of the plants in the rows treated on my plan were not, indeed larger, but vastly more numerous, and they were neither scabby nor affected with any disease whatever. A few had pushed (which was to be ascribed to a late rain,) and were apparently incompletely developed, while scab and wet rot attacked more and more the tubers of the other plants, which also fell off on the slightest handling.

"Although I am far from believing that I am able to explain the nature of the potato disease which has visited us of late years, yet I feel certain that I have discovered a means of strengthening the potato plant to such a degreea s to enable it to resist the influences which determine such diseases.

"Should any one be deterred from continuing the cultivation of potatoes, on account of the manipulation here recommended, which may be performed by women and even by children, I would remind him that the same field planted with potatoes is capable of supplying food to twice as many persons as when employed to growing wheat."—*From the Annals of Agriculture in Prussia, edited by the College of Rural Economy.*

Dr. Klotzsch presented to the King of Prussia a memorial offering to give to the world his method of preventing disease in potatoes, provided he were assured of a remuneration of 2,000 dollars, (about £300,) if, after three years experience it should be found efficacious.

The King handed the memorial to the Minister of the Interior, who requested the College of Rural Economy to discuss the matter with Dr. Klotzsch.

The president of the college undertook the arrangement, and, after Dr. Klotzsch had explained to him privately his method, reported most favorably of it to the College, which unanimously recommended that the very moderate remuneration asked for by Dr. Klotzsch should be secured to him on the following conditions, which were accepted by him.

1. That the College of Rural Economy should be the judges of the efficacy of the proposed method.
2. That their decision should be given, at latest, within three years, provided the potato disease against which the plants are to be protected, should appear during that period.

The Minister of the Interior approved of the recommendation, and authorized the College to conclude an agreement with Dr. Klotzsch.

The agreement has been concluded, and now the method is published that it may be tried and tested as widely as possible by comparative experiments, similar to those made by Dr. Klotzsch himself. The cost of it is stated not to exceed 1*s*. 6*d*. per acre in Germany.

It is very desirable that this method should be tried in the British Islands, and as the season for trying it now approaches, I have here given Dr. Klotzch's account entire.

William Gregory.

THE END.